The Wedge from Substituting Nuclear Power for Coal Power

A wedge can be achieved through substituting Nuclear power
- for coal: 700 GW that produces 5400 TWh, or
- for gas: 1400 GW that produces 10,800 TWh
- All of them have same capacity factor: 90%

Comments

In 1999, 351 GW of nuclear capacity were installed, and in 2000, the rate of production of nuclear electricity was 2586 TWh/y, for an average capacity factor (neglecting the one-year interval) of 84% (S33). Assuming that the wedge envisioned here is added to existing capacity which remains unchanged, we see that a wedge of nuclear power displacing coal requires approximately tripling, by 2054, both the installed nuclear capacity (adding 700 GW to 350 GW) and nuclear power output (adding 5400 TWh/y to 2600 TWh/y). The current challenge of nuclear waste disposal, in terms of mass of fission products, also grows by a factor of three.

The world's nuclear capacity today is far below what was expected in the 1960s, when nuclear power's promise as a substitute for coal was most highly regarded. Round numbers were used to project an installed nuclear capacity in 2000 of 1000 GW in the U.S. and 1000 GW in rest of the world. Problems of plant siting, uranium resource availability, and waste management were all addressed in that period, and no technical obstacles were identified. The U.S. currently has about ten times less nuclear capacity than then envisioned and the world as a whole has about six times less. Were the incremental 1600 GW to be built through steady construction over the next 50 years and be credited against baseload coal, this would account for roughly two wedges. Nuclear fusion reactors could account for some of this capacity, if fusion were to arrive on the scene faster than is now anticipated.

Nuclear fission power generates plutonium, as neutrons are absorbed by U^{238}. The rate of generation of plutonium depends on the reactor type and its operation. A light water reactor running on low-enriched uranium (the dominant reactor today) generates about 35 kg Pu per TWh of electricity[1], or 250 kgPu/y per installed GW, at 80% capacity factor. If our 2054 reactor has the same plutonium production rate per unit of thermal energy, but 50% efficiency and 90% capacity factor, it generates 180 kgPu/y. A wedge from nuclear power (700 GW) generates, in 2054, 130 tPu per year[2].

[1] We estimate this production rate from two inputs: 1) a ton of enriched uranium fuel generates about 35 GW_t-days of *thermal* energy before replacement (this is the "burn-up" of the fuel, expressed in its usual units), and 2) at replacement the spent fuel is about 1.0% plutonium (S42, Table 7.1, p. 109). Thus, the production of 10 kg Pu accompanies the production of 0.84 TW_th of thermal energy. At 32% efficiency converting thermal energy to electricity, the plutonium generation rate is 37 kgPu/TWh of electricity.

[2] Such a calculation is at best illustrative, because reactors in 50 years are unlikely to resemble today's light water reactors. They could produce either substantially more or substantially less plutonium than we have estimated.

To estimate the quantity of plutonium produced over the fifty years by the nuclear power plants that fill the wedge, we assume a linear ramp, so that, each year, 14 GW of new nuclear capacity are installed. Over 50 years, there are 17,500 GW-years of nuclear reactor operation. We can bracket the Pu produced while filling the wedge by observing that if all the reactors generated plutonium at today's estimated rate of 250 kgPu/GW-year, 4400 tPu would be produced, and if all the reactors generated plutonium at the rate we are estimating for reactors built in 2054, 180 kgPu/GW-year, 3200 tPu would be produced[3]. This addition of several thousand tons of plutonium to the world's stock can be compared with: 1) 1000 tPu, the current inventory in all the world's spent fuel; 2) 100 tPu, the current inventory in U.S. weapons; and 3) 10 kgPu, the critical mass of plutonium.

References

S33 International Energy Agency, 2002. *World Energy Outlook 2002*. Paris, France: OECD/IEA. By subscription**:** http://library.iea.org/dbtw-wpd/Textbase/nppdf/stud/02/weo2002_1.pdf.

S42 Bodansky, D., 1996. *Nuclear Energy: Principles, Practices, and Prospects*. Woodbury, NY: American Institute of Physics.

[3] One way to model our conjectured improvements in nuclear reactor efficiency and capacity factor would be to assume that the plutonium production per reactor-year depends linearly on the year that the reactor begins operation, falling linearly from 250 kgPu/GW-year to 180 kgPu/GW-year over the 50 years. For this simple model, 3500 tPu are produced while filling the wedge – indeed bracketed by 4400 tPu and 3200 tPu.