Reprocessing and Global (Energy) Security

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TEACHING THE NUCLEAR FUEL CYCLE
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Abstract

Reprocessing of light-water reactor (LWR) fuel has been practiced by France on its own behalf and on contract for Germany and Japan with the purpose of separating plutonium and uranium for recycle in LWRs. The separated Pu was initially intended for fueling plutonium-uranium (Pu-U) breeder reactors. In reality, the French program has been more costly than would have been direct disposal of used reactor fuel into a mined geological repository, but COGEMA has probably made a profit on the reprocessing of the foreign fuel. It is very much unfinished business, however, with most of the separated and vitrified fission products (and minor actinides), together with most of the separated Pu (in the form of 2 kg of plutonium oxide) in small welded steel cans. Although reprocessing and recycle is strictly necessary for breeder reactors, and for the "thorium fuel cycle," it adds to cost and hazard and wastes potentially valuable plutonium if the separation is done before there is an active and growing population of breeder reactors. The better approach is to store used LWR fuel elements in dry-cask storage for as long as 100-150 years, for eventual disposition in mined geological repositories, unless breeder reactors are developed that are as safe and more economical than LWRs. In the meantime, there is plenty of uranium to be mined in support of an expanded population of light-water reactors.

History

The UK also reprocessed Japanese LWR fuel under contract, but did a poor technical job of separation and vitrification of the fission products. The UK plant for the production of mixed-oxide LWR fuel (MOX) failed, and the British taxpayer is stuck with the job of cleaning up and fulfilling the contract after the failure of British Nuclear Fuels Limited—BNFL.

This sorry history has been well documented and cited in my books[1] and papers[2] most of which are available on my website, www.fas.org/RLG/.

I don't have time here to review the full technical details, but quote Phillip J. Finck, a key participant in the French reprocessing program and now Chief Nuclear Research Officer of the Idaho National Laboratory. According to Finck, under these circumstances reprocessing serves as a "delay line," adding another 15-20 years to the time before fuel can be transferred to the repository. A far better and cheaper way to delay the final disposition of spent fuel is dry-cask storage of the used fuel, either at the reactor or in more centralized dry-cask storage facilities. Because used MOX fuel itself has 6 times more radioactive heat than normal LWR fuel, it does not save space in the eventual repository.

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[1] E.g., *Megawatts and Megatons,* by G. Charpak and R.L. Garwin, 2001 and 2002; also *De Tchernobyl en tchernobyls,* by R.L. Garwin, G. Charpak, V. Journé (2005)

[2] http://www.fas.org/rlg/120911%20The%20Future%20of%20Nuclear%20Energy2.pdf, and http://www.fas.org/rlg/2011%20Erice%20Fukushima1a.pdf

Reprocessing of what form of spent fuel to what form of new fuel?

The French plant at La Hague, the UK plant at Sellafield, and the Japanese plant at Rokkasho were all designed to separate highly radioactive fission products from the 1% plutonium content of spent fuel (10 kg per ton) to the extraordinary level of 1 part in 10 million of retained fission products. This remarkable accomplishment allows the PuO_2 to be handled "by hand" in a glove box rather than behind thick radiation shields by remote control. For use in LWRs, the MOX fuel is produced by sintering plutonium and uranium oxides and machining the rough pellets to fit accurately into the zirconium alloy tubing (sheath) to make a fuel rod 500-cm long. But the PuO_2 cans can safely be carried for hours in bare hands and close proximity to anyone who can steal them, and can be used readily to make plutonium metal for use in a nuclear weapon that will have at least 1-2 kilotons (thousands of tons) of high-explosive equivalent yield, and even full yield of 20 kilotons like the Nagasaki bomb. Some 6 kg of Pu was used in that weapon, and somewhat more of power-reactor Pu would be required.

Current proposals for breeder reactors by GE-Hitachi, and by Terrapower LLC, propose to use "metal fuel" in which the Pu is alloyed with uranium or zirconium and fits into precisely specified zircaloy or stainless steel sheaths, with the small space between metal fuel and sheath filled with molten sodium metal. Rather than aqueous processing with strong acids, the used fuel from the breeder would be treated by "pyroprocessing," using electrolysis of the metal fuel in molten salt, which would produce highly radioactive mixtures of Pu and U, which would then be adjusted by the addition of depleted uranium to form new fuel to be cast into fuel pins or pellets and sheathed and sealed into fuel rods to form new fuel elements for the breeder reactor.

"Tremendously important, though[3]*, is informed analysis, as contrasted with R&D. That is, buyers and users need to model and to simulate their possible options. Some oppose the use of nuclear power because of its potential for the proliferation of nuclear weapons to additional states or to terrorist organizations. Others oppose it because of the potential for large-scale accidents or its vulnerability to terrorist attack. The nuclear power sector, however, is not homogeneous. Reactors themselves, if they operate with leased fuel so that there is no need for enrichment and no need for disposal of spent fuel locally, do not contribute to nuclear proliferation. For years I have urged changing laws and custom to permit disposal of spent nuclear fuel outside the borders of the country in which it was generated, and the licensing and supervision by the International Atomic Energy Agency—IAEA—of competitive, commercial, mined geologic repositories. These would accept, for a fee, spent*

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[3] These italicized paragraphs from my presentation of April 2009: http://www.fas.org/rlg/042209%20R&D_Opportunites_and_Needs2.pdf

fuel in IAEA-approved disposal casks or reprocessed spent fuel in similarly approved overpacks.

"I also recommend the equivalent of a world breeder reactor laboratory, with the purpose of working on three quite specific choices of breeder reactor, including their fuel form and fuel cycle. This laboratory would develop and use an advanced and evolving state-of-the-art suite of computer simulations tools, with the purpose of providing reliable simulation and modeling of the performance of each of the reactor types. If, after 10 or 20 years, the effort yielded a proposed system that was demonstrated in credible simulation to be as safe as existing light-water reactors and economically competitive with them, then a prototype could be built to verify the simulations. I believe that this is the way to make progress most rapidly in this important sector, but it is, obviously, only one of the approaches that we could have been following all these years, and it won't help at all for 20 years or more."

Harold M. Agnew, in a 1976 article in The Bulletin of Atomic Scientists proposed leasing of power reactor fuel, rather than its sale, in order to control proliferation. Of course, that would require the supplier to take back and dispose of used nuclear fuel.

In February, 2006, President George W. Bush announced the Global Nuclear Energy Partnership—GNEP—under which the United States would lease fuel to other states and reprocess the returned fuel, burning its plutonium in an array of fast-neutron "burner" reactors, which, technically, would fission the "minor actinides" as well, which accumulate if the Pu is used to fuel thermal-neutron reactors.

Government proponents of GNEP aimed to break ground on reprocessing plants by the end of 2006, but it was, fortunately, not to be. My 2006 testimony on GNEP provides details[4]. According to designs by General Electric and others, a fast-neutron reactor with "conversion ratio" less than 65% cannot be made safe and controllable; therefore, the burner population would need to dispose of 3 times as much plutonium as had been advertised, and rather than disposal means, the fast reactors would be the dominant energy producers.

Fuel leasing and take-back is a good idea, but it has little traction in the United States, where there is now no program to develop a mined geologic repository—Yucca Mountain having, regrettably, been taken off the agenda by President Obama.

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[4] http://www.fas.org/rlg/060406-gnep_slides.pdf and http://www.fas.org/rlg/062606GNEP5_1.pdf

An MIT fuel cycle study (2011) provides a wealth of information, e.g.,

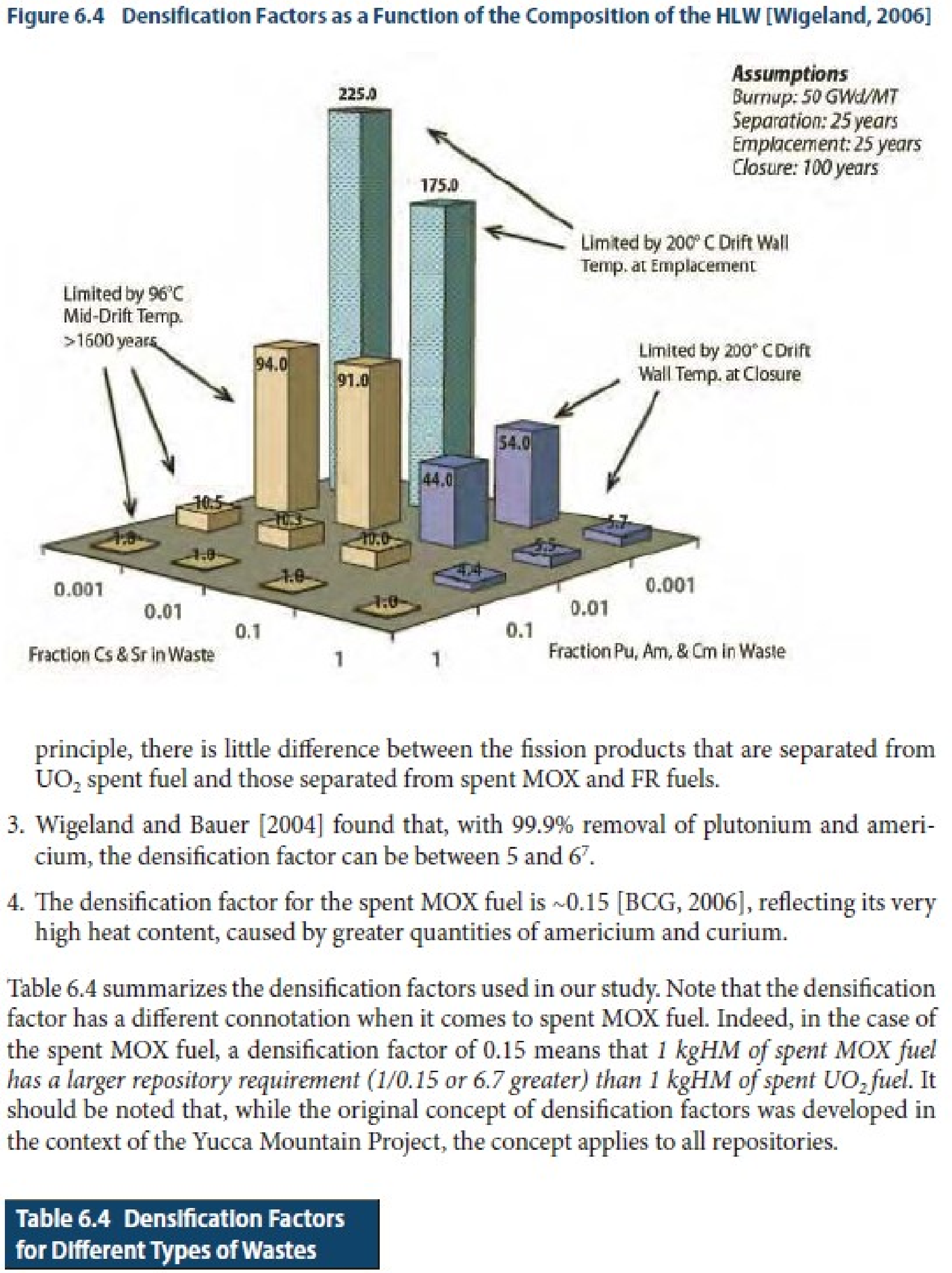


Figure 6.4 Densification Factors as a Function of the Composition of the HLW [Wigeland, 2006]

principle, there is little difference between the fission products that are separated from UO_2 spent fuel and those separated from spent MOX and FR fuels.

3. Wigeland and Bauer [2004] found that, with 99.9% removal of plutonium and americium, the densification factor can be between 5 and 6[7].

4. The densification factor for the spent MOX fuel is ~0.15 [BCG, 2006], reflecting its very high heat content, caused by greater quantities of americium and curium.

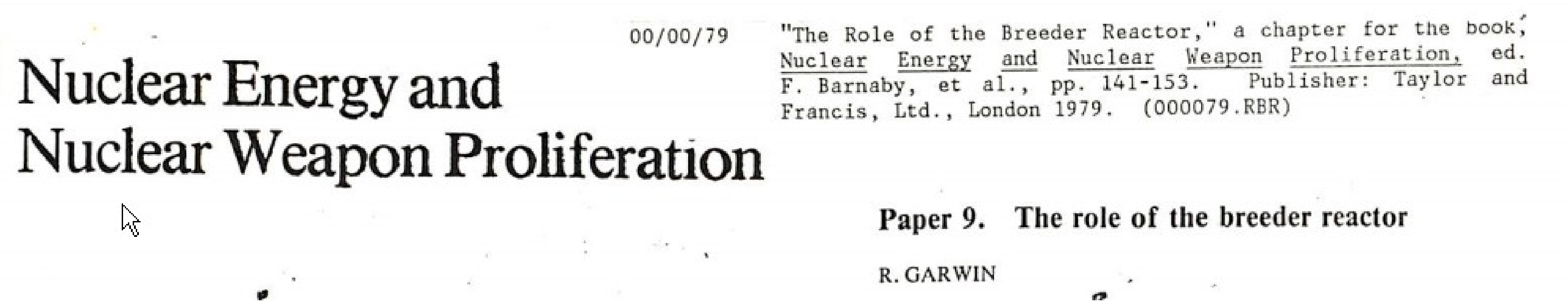
Table 6.4 summarizes the densification factors used in our study. Note that the densification factor has a different connotation when it comes to spent MOX fuel. Indeed, in the case of the spent MOX fuel, a densification factor of 0.15 means that *1 kgHM of spent MOX fuel has a larger repository requirement (1/0.15 or 6.7 greater) than 1 kgHM of spent UO_2 fuel*. It should be noted that, while the original concept of densification factors was developed in the context of the Yucca Mountain Project, the concept applies to all repositories.

Table 6.4 Densification Factors for Different Types of Wastes

Here I call attention, though, to its conclusion that an expanding population of breeder reactors can and should be fueled initally with enriched uranium, and also that recent designs establish that enrichment can be limited to the LEU range—i.e., < 20% U-235.

> *Contrary to expectation, employing enriched uranium in the startup of fast reactors actually enables uranium savings compared to the traditional, TRU-fueled fast reactor fuel cycle (see Figure 6.17). This is because using enriched uranium to start FRs allows an early phaseout of light water reactors, which ends up reducing demand for mined uranium. (p. 94).*

In fact, this is far from a new idea, as evidenced by my own publications in the 1970s[5], from of which I take this title and paragraph,



00/00/79 "The Role of the Breeder Reactor," a chapter for the book, Nuclear Energy and Nuclear Weapon Proliferation, ed. F. Barnaby, et al., pp. 141-153. Publisher: Taylor and Francis, Ltd., London 1979. (000079.RBR)

Nuclear Energy and Nuclear Weapon Proliferation

Paper 9. The role of the breeder reactor

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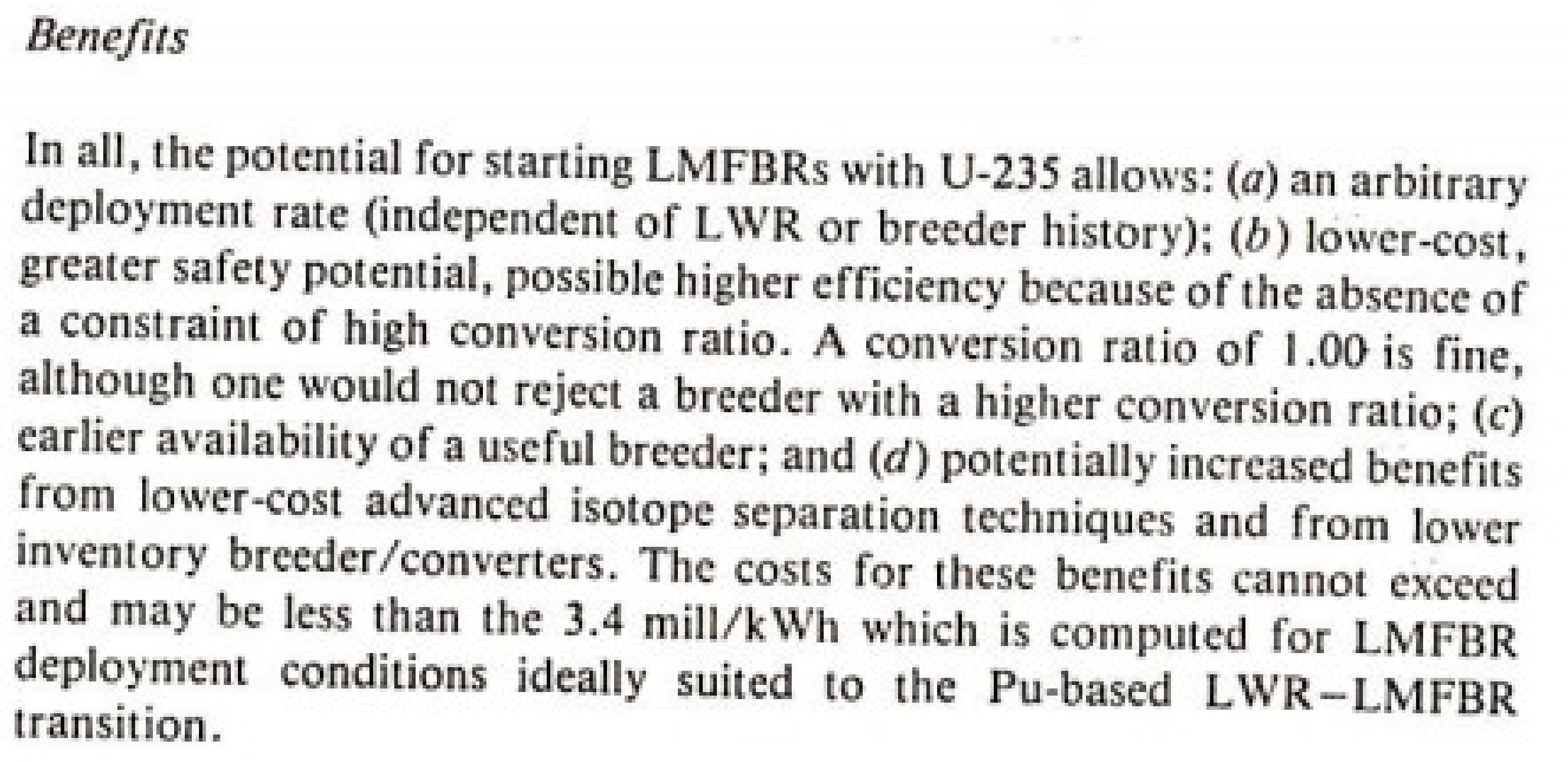
[5] E.g., http://www.fas.org/rlg/000079.RBR%20The%20Role%20of%20the%20Breeder%20Reactor.pdf



Benefits

In all, the potential for starting LMFBRs with U-235 allows: (*a*) an arbitrary deployment rate (independent of LWR or breeder history); (*b*) lower-cost, greater safety potential, possible higher efficiency because of the absence of a constraint of high conversion ratio. A conversion ratio of 1.00 is fine, although one would not reject a breeder with a higher conversion ratio; (*c*) earlier availability of a useful breeder; and (*d*) potentially increased benefits from lower-cost advanced isotope separation techniques and from lower inventory breeder/converters. The costs for these benefits cannot exceed and may be less than the 3.4 mill/kWh which is computed for LMFBR deployment conditions ideally suited to the Pu-based LWR–LMFBR transition.

But if nuclear power is to survive to play an expanded role in our energy future, the regulators and operators must ensure a reasonably safe and secure operation, and the public must be educated to accept a low but finite risk of accident, as discussed in a recent presentation[6]. In particular, although on the basis of the BEIR-VII study of The National Academies (2007) I estimate a cancer death toll from Fukushima Daiichi that will amount to about 1500, forced evacuation to avoid further exposure would probably cause more deaths and disease.

(This estimate is of cancer deaths from Fukushima Daiichi is fully documented in my presentation "Evaluating and Managing Risk in the Nuclear Power Sector," cited below, with data from the French Institute of Radioprotection and Nuclear Safety (IRSN), but using data for the entire local population and not for more limited sub-populations and times. According to the IRSN data, this estimate is a lower bound.)

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[6] www.fas.org/rlg/Evaluating%20and%20Managing%20**Risk**.pdf and http://www.fas.org/rlg/2011%20Erice%20Fukushima1a.pdf