April 4, 2007

The Role of Fast-Neutron Reactors in the Treatment of Nuclear Waste and a Major Expansion of Nuclear Power Worldwide

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For presentation at Mini-Symposium on Nuclear Technology
Eisenhower Institute, Washington, DC, April 9, 2007

I have long been involved with nuclear reactors and fast-neutron reactors in particular, beginning with my work on thermal reactors at Los Alamos for rocket propulsion. In 1978 I prepared a paper "The Role of the Breeder Reactor," published in a SIPRI volume,[1] and presented similar views at Argonne National Laboratory and various university centers in the United States at that time.

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[1] "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.

More recently in writing my books on nuclear power in French and English (with Georges Charpak and now with Venance Journe), I took up fast reactors once again and focused on them with the advent of the GNEP program in February, 2006.

As you know, GNEP emphasizes fast reactors for the treatment of the the transuranic-- TRU-- waste from thermal power plants and proposes to begin reprocessing as soon as possible the spent fuel from U.S. thermal power reactors.

Much of the substance of this talk is taken from my presentation of March 27, 2007 to a session of the American Chemical Society in Chicago. My conclusions are that the cost of GNEP is unknown, but understated in view of the assumption of a conversion ratio-- CR-- of 0.25 for the fast-neutron reactors rather than the CR=0.65 stated by General Electric to the DOE-sponsored study at the National Academy of Sciences, as the minimum practical value.

Second, the nonproliferation goals of GNEP have been compromised, but not by the secure fuel cycle which I support (the guaranteed leasing of LEU fuel to reactor operators, with the take away of spent fuel by the same supplier country or by another). In fact, there never was a credible "proliferation resistant" reprocessing/recycle proposal in GNEP, and it made no sense for deployment in the United States from the nonproliferation point of view and was not sufficiently proliferation resistant to be allowed or proposed for deployment in other states. But now we have pretty much the worst of all possible worlds, with COEX probably the leading candidate for reprocessing in the United States, dubbed "proliferation resistant" because it does not "separate pure plutonium" but has it mixed with an equal amount of uranium, more or less.

The point is that plutonium is readily separated from uranium and to acquire 10 kg of civil-Pu, one would need to carry away only 20 kg of the COEX product, with no significant gamma radiation emitted. The comparison of the IAEA-defined self-protecting radiation field of 100 rem/hr at a distance of 1 meter shows a shortfall by a factor 10,000 or so between the spent fuel elements themselves and the COEX or PUREX product.

In short, my view of the initiation of reprocessing of LWR fuel in the United States is that it is a great mistake, diversion, and would very likely impair the so-called nuclear power renaissance in the United States. Almost unmentioned is the requirement to hold separated strontium and cesium above ground for 200-300 years, probably in passively cooled dry-cask storage, just as the once-through cycle should hold unprocessed spent fuel elements in casks of similar size and number.

As I have indicated in much congressional testimony and many talks and presentations in the United States, as well as in discussions with DOE representatives, it seems very likely to me that GNEP, by design or in fact, would likely have the result of installing a very large fast reactor population in the United States, and if that is the case, that it be done intentionally and not as a side effect of an attempt to "manage waste" from the LWRs. In fact, I call attention to the recent paper by Robert Dautray and Jacques Friedel that specifically rejects the application of fast reactors and advocates, instead, a frontal attack on the problems of fast reactors so that they could be deployed before the end of this century as the mainstay of nuclear power production.

My strong recommendation is that if fast reactors are to be considered for the disposition of TRU from LWRs then most of the GNEP funds should be spent on three competitive designs of fast reactors, each associated with its own specific fuel form and reprocessing approach. After all, a gas-cooled fast reactor with metallic fuel would have very different design requirements and reprocessing than would a carbide-fueled lead-cooled reactor. In this approach of using fast reactors to "treat" LWR spent fuel, unless the CR can be held to 0.25 or lower, the fast-reactor population is likely to have an electrical power output greater than that of the LWRs, and being deployed at higher cost with the necessity of continual reprocessing of the FR fuel, one asks whether the tail is not wagging the dog.

Much more straightforward is the goal of ultimately displacing the LWRs and other thermal reactors with fast breeder reactors, but this is a totally different goal, since one wants to have a CR > 1.0 rather than a CR as low as possible.

For the breeder approach, as I have argued for the last 30 years, the requirement is not so much the highest possible CR, which would in any case lead to a rather slow growth of the fast reactor population, but for a low-inventory breeder, so that more of them could be deployed with a given stock of Pu or with a given stock or rate of production of enriched uranium for their initial cores.

Ultimately, though, it is cost and safety of the breeder reactor that is important in competition with LWRs. So I do propose an international focus on fast-neutron breeder reactors, which would automatically solve the problem of supply of uranium.

I have discussed a population of 9000 1-GWe reactors to move the world from 20% supply of electrical energy to 100% of the current supply (a factor 5 above current reactor population), plus a doubling of the electrical supply, and also the replacement of much of the non-electric energy supply by nuclear power.

Under these circumstances, at a consumption of about 200 tons per year of natural uranium per GWe reactor, the consumption would be on the order of 1.8 million tons of uranium per year, which would be laughable with a uranium reserve often stated as 4 millions tons. But the Gen-IV analysis for cost vs. supply of uranium indicates that there would be 170 million tons of terrestrial uranium at a price of $260/kg. Whatever the prospects for breeder reactors, it is of the utmost urgency for the nations of the world (and, for instance, for the United States) to invest some tens of millions of dollars to determine the "supply curve" for uranium from terrestrial sources-- that is, the cost per kg of natural uranium as a function of millions of tons produced. And it is essential also to understand the cost of acquiring uranium from seawater, where there is some 4500 million tons. That cost is surmised in the Red Book to be on the order of $300/kg of uranium.

The cost of uranium from seawater has enormous impact on the economics and approach to nuclear power, especially if it is less than the $700-1000/kg that would be ascribed to the saving of natural uranium by recycle of plutonium in LWRs.

It is natural to ask whether an international consortium might be formed to build a prototype economical fast-neutron breeder, in analogy with ITER. And here my answer is for the moment "no."

What might be done, however, is to have an international consortium that takes more seriously than Gen-IV the prospects of a breeder reactor, and instead of having individual focus in the participating nations on one or another reactors, could have a joint activity for the EXPLORATION (not demonstration) of an economical breeder reactor. That is, many sodium-cooled fast reactors have been built in the world, only to show that they are more costly than LWRs. What is needed is a focus on reducing the cost of the breeder reactor, capitalizing on the fact that the liquid-metal coolant (that or sodium) need not be at high pressure-- in contrast with water in an LWR.

But at the same time that there is a focus on cost of the breeder, there would need to be intense and open analysis on the possible accident scenarios, bearing in mind Edward Teller's caution that[2]

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[2]Edward Teller, "Fast Reactors: Maybe." Nuclear News (August 21, 1967).

"For the fast breeder to work in its steady-state breeding condition you probably need something like half a ton of plutonium. In order that it should work economically in a sufficiently big power-producing unit, it probably needs quite a bit more than one ton of plutonium. I do not like the hazard involved. I suggested that nuclear reactors are a blessing because they are clean. They are clean as long as they function as planned, but if they malfunction in a massive manner, which can happen in principle, they can release enough fission products to kill a tremendous number of people.

...But, if you put together two tons of plutonium in a breeder, one tenth of one percent of this material could become critical.

I have listened to hundreds of analyses of what course a nuclear accident can take. Although I believe it is possible to analyze the immediate consequences of an accident, I do not believe it is possible to analyze and foresee the secondary consequences. In an accident involving a plutonium reactor, a couple of tons of plutonium can melt. I don't think anybody can foresee where one or two or five percent of this plutonium will find itself and how it will get mixed with some other material. A small fraction of the original charge can become a great hazard."

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