# GNEP and
# Plutonium Recycle in the US Nuclear Power System

Richard L. Garwin
IBM Fellow Emeritus*
(*Personal views. Affiliation given for identification only)
Thomas J. Watson Research Center
Yorktown Heights, NY 10598
RLG2 at us.ibm.com, (914) 945-2555, www.fas.org/RLG/

A briefing for House staff
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Today some 103 nuclear power plants in the United States produce about one million kilowatts each of electrical power, supplying some 20% of US electrical needs.  They do this by the use of the neutron chain reaction in uranium-oxide ceramic pellets, sustained by the regeneration of neutrons through the fission process. Each fission in the light isotope of uranium—U-235 that constitutes 0.7% of natural uranium and is enriched to about 5% concentration in the 25 tons of fuel loaded into the reactor each year, where it produces heat for about 85% of its 4-year sojourn—liberates about 2.5 neutrons on the average, and 30 billion fissions contribute about 1 joule of heat. If your personal computer runs at 3GHz or 3 billion operations per second and consumes about 50W or 50J/s, it is fed by about 150J/s of reactor heat or 4,500 billion fissions per second—about 1500 fissions per arithmetic operation, or about 20 fissions per bit.

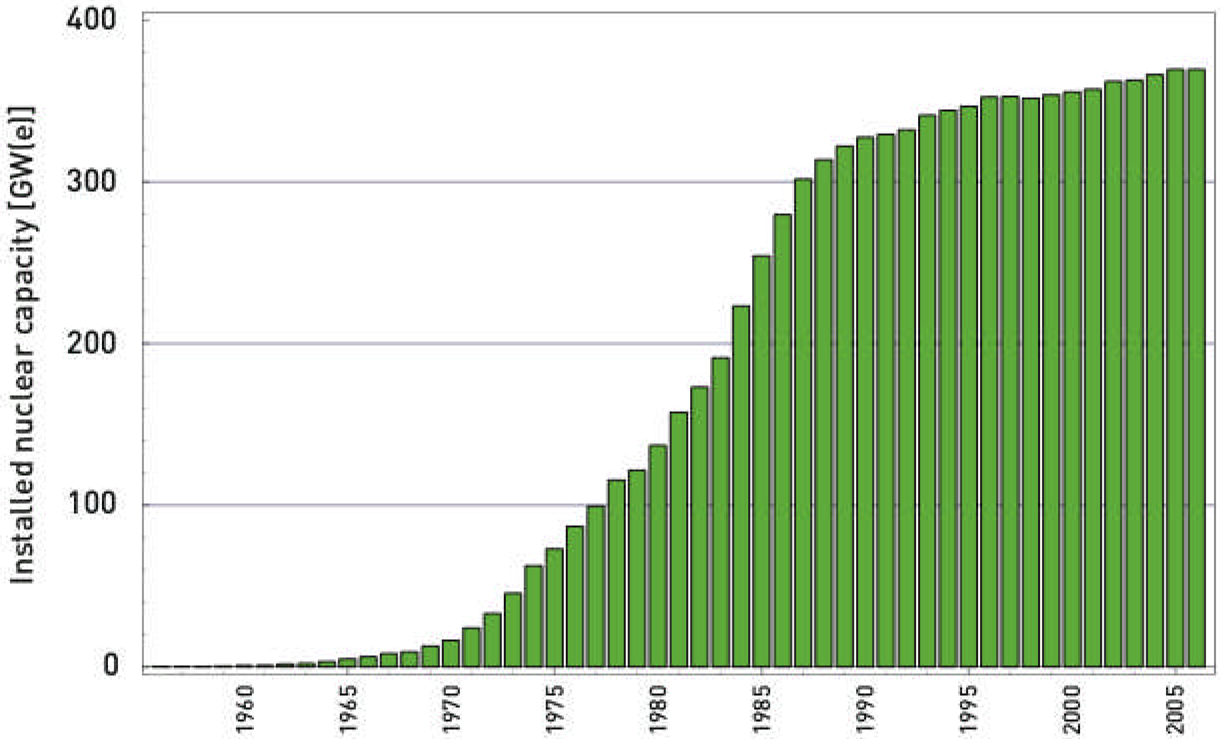


Fig. 1 Installed nuclear capacity (GW(e))[1]

[1] Frank von Hippel, "Managing Spengt Fuel in the United States: The Illogic of Reprocessing" Research Report No. 3, International Panel on Fissile Materials, January 2007 (at www.fissilematerials.org

Of the 25 tons of fuel--*heavy metal*-- loaded each year into the reactor as essentially non- radioactive fuel rods and fuel elements, about one ton is *fissioned* during its 4-yr stay in the reactor— that is, the U-235 is split into a light and a heavy *fission product* largely retained in the solid fuel pellets in their tubular metal sheaths. The accompanying heat is transferred to water in the high-pressure reactor vessel, and the water boils to steam in the upper portion of the vessel (for a boiling water reactor—BWR) or after a heat exchanger in the case of a pressurized water reactor—PWR.

Because these reactors use ordinary water both to transfer heat from the reactor fuel to the steam turbine, they are called *light-water reactors—LWRs*. The plentiful U-238 does not fission to a significant extent in LWR, but it does have an appetite for the slow neutrons; instead of fission U-238 undergoes *capture* of a neutron to form U-239, which in short order decays in the reactor to Np-239 and then to plutonium—Pu-239. Pu-239 is even more readily *fissile* than is U-235 and is quite suitable for making nuclear explosives, as is highly enriched U-235 in the range of 80% U-235 or more[2].

The *spent fuel* elements removed from the reactor in the refueling operation are highly radioactive.  Even after

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[2] "Management and Dispostion of Excess Weapons Plutonium," Committee on International Security and Arms Control, pp. 32-33, (1994), (at www.nap.edu/catalog/2345.html)

100 years they are regarded as *self protecting* in that a single fuel element would irradiate a person at one meter distance with more than a dose of 1 *sievert* (1 Sv) in 1 hour. Delivered in an instant, a lethal dose of 4Sv would raise the body temperature only about 0.001ºC.

Within the operating reactor, each kg of fuel generates about 30kW of heat. A week after reactor shutdown, fuel elements transferred to the spent-fuel pond still generate about 100W/kg, from the decay of the radioactive fission products. If the water were lost, the spent fuel would heat within hours to the melting temperature of the fuel-rod sheath; the zirconium alloy would burn in air. After 10 years, spent fuel still creates 2W/kg, little enough that the fuel can be stored in massive casks to protect people from the gamma radiation of the fission products; the casks are cooled by natural air convection.

All US power reactors are fueled with low-enriched uranium—*LEU*—ceramic fuel, and almost all spent fuel thus far has been held in at-reactor water pools that provide cooling of the fuel elements and shielding of plant and public personnel against nuclear radiation. It has long been planned that after 10 years or so of pool storage and cooling, fuel elements would be transferred to long-term storage casks that would then be shipped to the Yucca Mountain, Nevada, mined geologic repository; a recent National Academies study provides an independent assessment of the safety of such shipment[3]. Following the long-delayed opening of YM, fuel elements in storage casks would be loaded into the underground horizontal tunnels—*drifts*—with about 1.1 metric tons of initial heavy metal per meter length of drift—MTIHM/m. The US industry in this way has been practicing the *open fuel cycle* or the *once-through* or *direct disposal* fuel cycle—at least up to final disposal in a mined geologic repository.

In contrast, for decades France has been *reprocessing* spent fuel from its 58 LWRs, using the PUREX process

[3] "Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States" The National Academies Press, Feb. 2006 (http://books.nap.edu/catalog/11538.html)

to separate about 16 tons per year of plutonium from about 1600 tons of spent fuel.  Much of the spent fuel was of German or Japanese origin, and the separated Pu and *vitrified* fission products were by law and contract to be returned to the country of origin. France has used its own Pu to fabricate mixed-oxide—*MOX*—ceramic fuel pellets that displace LEU fuel elements—*UOX*—and thus reduce the uranium demand by about 20%.

PUREX was used by the US and other states to separate plutonium for nuclear weapons from lightly irradiated fuel from Pu-production reactors; less than one ten-millionth of the radioactive fission products remains with the separated Pu.  The civil plutonium is stored and shipped in small welded stainless-steel cans containing 2 kg of plutonium oxide. In contrast to the fierce gamma radiation of the spent fuel, so little radiation emerges from the pure plutonium oxide that the cans can be carried without harm in one’s bare hands, and the MOX fuel elements can be fabricated without the use of heavy shielding. However, plutonium is an intense emitter of alpha particles and must therefore be handled in a *glove box* to prevent ingestion or inhalation. Per gram, weapon plutonium emits about 60,000 times less alpha radiation as does the polonium-210 that killed Alexander Litvinenko in 2006; this is a consequence of the 24,000-yr half life of Pu-239 compared with the 140-day half life of Po-210.

The French approach to the *closed fuel cycle* has been demonstrated by French government analyses to be more costly than the open fuel cycle.

**Table 2. Spent-fuel disposal costs in four scenarios for the French Fuel Cycle[61]**
**(Billions of 2006 $, 58,000 tons of spent fuel)**

| | Percentage of Spent LEU Fuel Reprocessed | | | |
|---|---|---|---|---|
| | 100% (Derived scenario) | 67% | 27% (Reprocessing ends in 2010) | No Reprocessing |
| **Back end costs** | 84 | 74 | 61 | 41 |
| **Front end cost savings from plutonium recycle** | -10 | -8 | -2 | 0 |
| **Net costs** | 74 | 66 | 59 | 41 |

Fig. 2. Spent-fuel disposal costs in $billion per 58,000 tons of spent fuel[4]

[4] Frank von Hippel, *op cit.*

Despite persistent claims that this approach to plutonium recycle has substantial benefits in reducing the burden on the repository, there has been recent awareness that the capacity of the repository is not limited by the bulk of the spent fuel but by the continuing heat evolution from the fission products and the *transuranics*—that is, plutonium, americium, neptunium, curium. This is clear from two highly authoritative books by Robert Dautray, former high commissioner of the French Commisariat à l'Energie Atomique—CEA. More accessible is the recent presentation

# Spent Nuclear Fuel Management Options

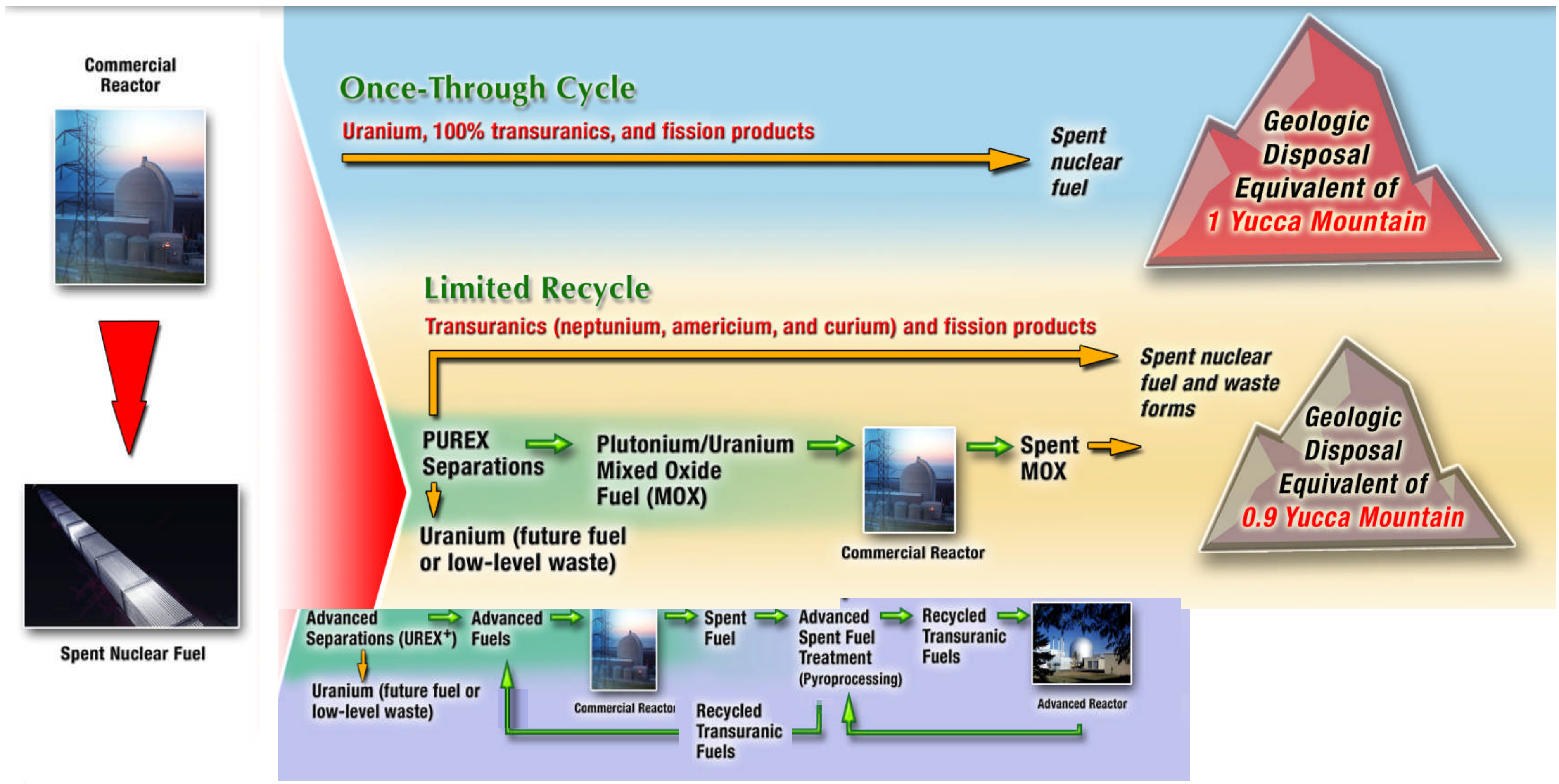


Fig. 3. Pu recycle as practiced in France would still require "0.9 Yucca Mts"[5]

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[5] Phillip J. Finck, "**Technologies** for Advanced Fuel Cycles" presented at The National Academies, October 17, 2006.

showing that "Limited Recycle" with the disposal of the spent MOX fuel into the repository requires 90% as much repository capacity as does direct disposal without reprocessing. Dr. Finck, who worked in the French program and is now a key technical person in the US Global Nuclear Energy Partnership—*GNEP*—stresses that major gains in repository capacity can be achieved only with a suite of fast-neutron reactors that can actually fission the transuranics—the *minor actinides*. This has never been made clear by the French nuclear-power entities.

GNEP was announced by President George W. Bush in February, 2006[6]. Testimony by the Department of Energy at the April 6, 2006 session of the Energy Subcommittee of the House of Science Committee highlighted the fact that of the proposed first-year GNEP budget of $250 M, some $155 M was toward the building of a demonstration reprocessing plant, dubbed UREX+. The intent was to demonstrate at perhaps 10% full-scale the reprocessing of all the fuel emerging from the 103 operating US LWRs, in order to begin to provide fuel for a generation of fast-neutron Advanced Burner Reactors—*ABRs*. A key element of GNEP was to have a reprocessing approach more "proliferation

[6] My own position on the evolving GNEP program has been available at www.fas.org/RLG//, including testimony and slides of April 6, 2006 and a presentation of Octobe 17, 2006 to an October 17, 2006 session of a committee on Internationalizing the Nuclear Fuel Cycle.

resistant" supposedly by leaving enough fission products with penetrating gamma radiation—*lanthanides*—especially europium-154 with a half-life of 8.8 years.

Part of the GNEP program is to offer foreign reactor operators a *secure fuel cycle* at advantageous rates—leasing of fresh fuel and take-back of the spent fuel—and also *cartridge reactors* that would be delivered loaded with fresh fuel and could operate for 20-30 years without refueling.  The cartridge reactor would then be replaced by a fresh one and taken back for de-fueling. I strongly support these aspects of GNEP, observing, however, that the U.S. will be far from the only one to offer cartridge reactors or the secure fuel cycle.

Still, national and international regulations and customs need to be changed in order to permit spent fuel to be transferred from one country to another for ultimate disposition, either by direct entombment in a mined geologic repository or by reprocessing followed by entombment in a repository. The secure fuel cycle makes good sense economically from the point of view of the using country, and for the world from the point of view of limiting facilities capable of providing weapon-usable materials: enrichment plants and reprocessing plants that, respectively, produce enriched uranium (and could produce highly enriched uranium), and the reprocessing plant that produces plutonium, even if it is mixed with 50% uranium in some of the recent proposals. The proposal to lease and take back reactor fuel was published long ago by Harold M. Agnew, then Director of the Los Alamos Scientific Laboratory, in the Bulletin of the Atomic Scientists (May 1976, page 23), as "Atoms for lease: An alternative to assured nuclear proliferation."

States that express concern about the reliability of future fuel supply under potentially tense international conditions could well buy a stockpile of LEU fuel for 10 years of operation of their reactors; fortunately, LEU fuel is safe and cheap to store and cheap to buy, in comparison with fossil fuels.

Beyond the provision for the US to join other supplier states in a secure fuel cycle without commitment to reprocessing, I believe that GNEP has its priorities all wrong.  GNEP as formulated and presented at the hearing of April 6, 2006 is not necessary to achieve the stated goals of nonproliferation and is more likely to *hinder* the achievement of those goals.

According to DOE announcements of August, 2006, the DOE is planning to replace the proposed engineering-scale demonstration—*ESD*—plant with a purchased conventional reprocessing plant very much like the one that has just begun operation at Rokkasho-mura, Japan. Except that the DOE plant would be the largest in the world. Although it would not separate "pure plutonium" if it operates like Rokkasho, the extracted pure plutonium oxide would be mixed with about an equal amount of uranium oxide. This would add little to the cost or time required for a state or terrorist to convert a stock of this *COEX* product into plutonium metal for a nuclear weapon.

As for terrorist acquisition of nuclear weapons, to acquire plutonium from spent fuel elements is a daunting task because of their intense radioactivity and the fact that to obtain the 10kg of reactor-grade Pu for a nuclear weapon a terrorist would need to steal and reprocess a ton of intensely radioactive spent fuel. In a reprocessing world, the task is to acquire 10kg of separated Pu (from the PUREX process) or 20kg of COEX product, either of which can be carried off without additional shielding. Despite the fact that the GNEP reprocessing product is less proliferation resistant than the direct-disposal approach, in GNEP-speak the claim of proliferation resistance features importantly in the arguments for GNEP.

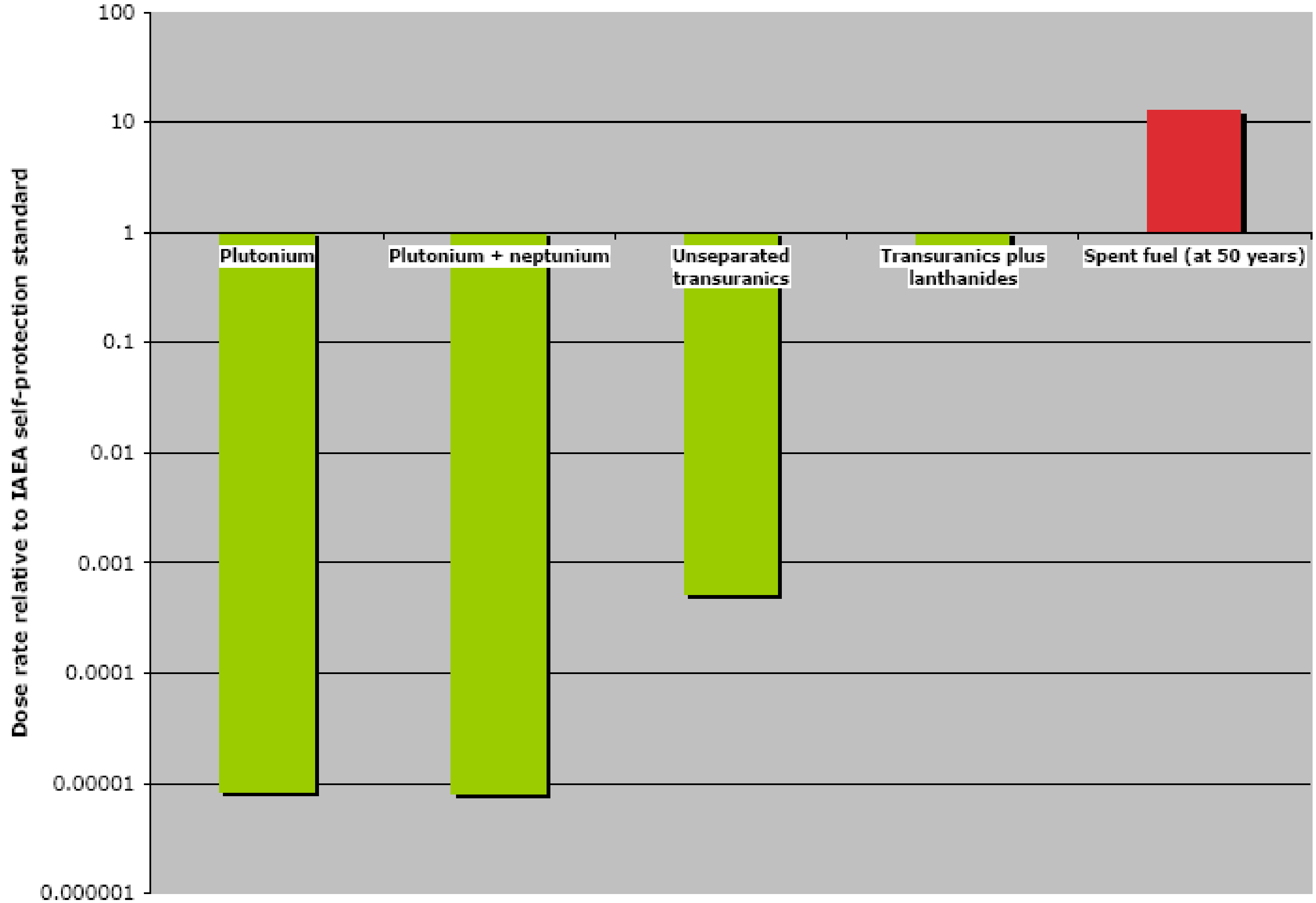


**Figure 7. Factors by which dose rates from 1-kg spheres of transuranic metal produced by various versions of UREX+ fall short of the IAEA threshold for self protection** (1 Sievert or 100 rems per hour at one meter). For example, the dose rate from unseparated transuranics is about 0.001 or one thousandth of the self-protection standard. [69]

Fig. 4. Factors by which dose rates fall short of "self protection"[7]

[7] Frank von Hipple, *op cit.*

France and Japan have often supported their activity in reprocessing and recycle of plutonium by pleading that they lack native energy resources and need reprocessing in order provide some degree of energy independence. This argument does not hold water, since the recycle of Pu in LWRs (or the use of the ideal ABR—one that consumes every plutonium atom without producing another—to burn up the actinides) reduces uranium needs by only about 20%, at best. I must say, however, that I have been notably unsuccessful in dissuading either country over the decades by the argument that far *more* energy independence would be obtained by buying ahead an 8 or 10-year stock of uranium fuel, and the *same* degree of energy independence would be achieved by buying ahead 20% of a 10-year stock of fuel.

This saving of uranium comes at a very high price. Assuming a reprocessing cost of $1000/kg of spent fuel, and noting that 5 kg of spent fuel must be reprocessed for each kg of MOX fuel produced (that is, 5 spent fuel elements for each fresh MOX fuel element), it is a simple matter to calculate the cost per kg of uranium saved.  Each kg of fresh fuel element (5% U-235) requires 9 kg of natural of uranium, although less NU would be required if the tails concentration from the enrichment plant were reduced, as would naturally follow from the higher price of uranium.  Nevertheless, at 9kg of NU per kg of LEU, the break-even cost of uranium as contrasted with reprocessing would be \$5000/9 = \$555/kg of NU.  In reality, the fabrication of a MOX fuel element, given the MOX material is far more expensive (by about \$1000/kg) than is the fabrication of a UOX fuel element.  So the break-even cost of NU that would make reprocessing and recycle in LWRs a wash is thus about \$555 + \$1000/9 = \$666/kg of natural uranium.  For comparison, I show the historical cost of uranium.

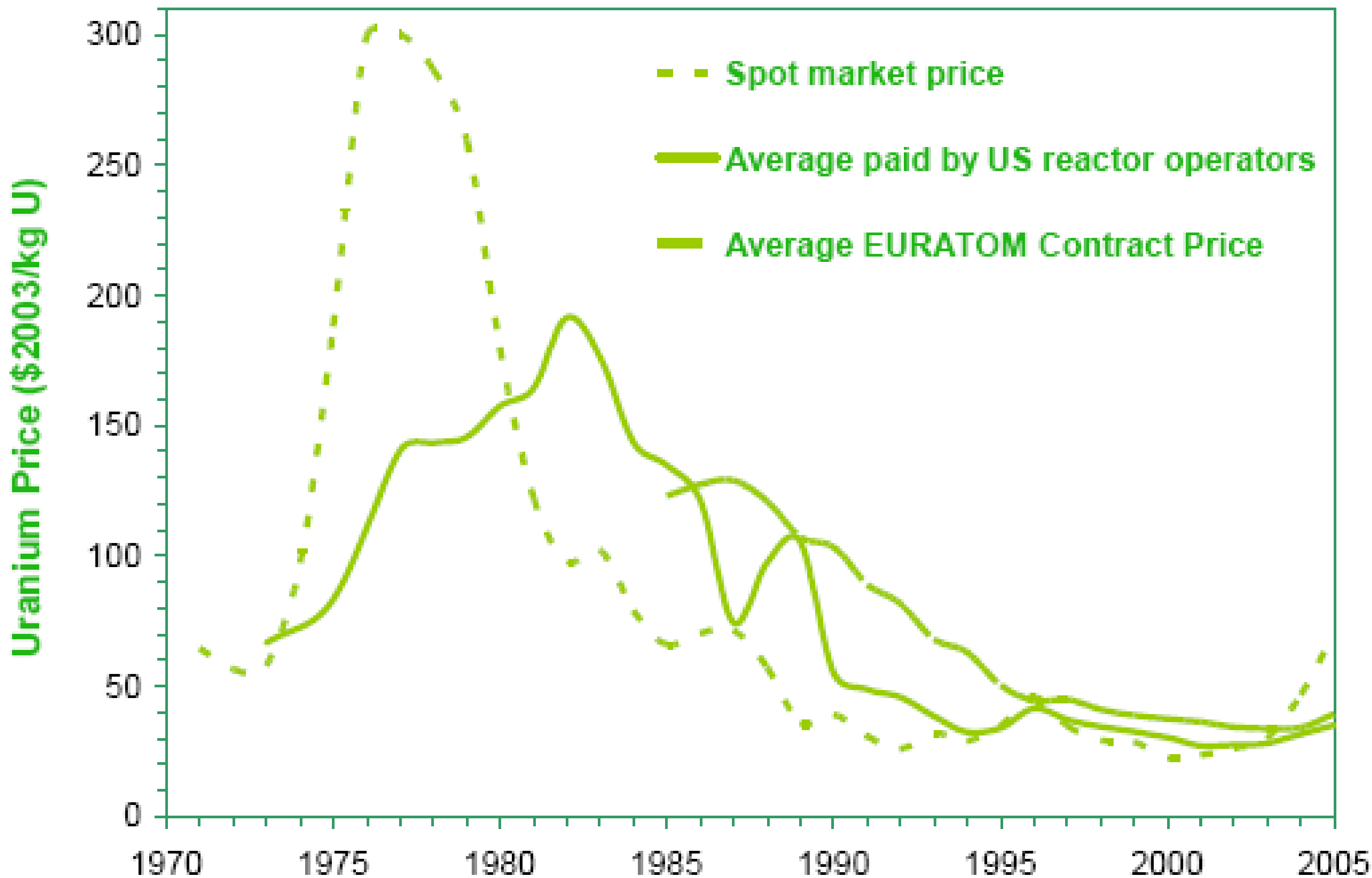


**Figure 3. Average and spot uranium prices** in constant 2003 dollars, 1971-2005.[18]

Fig. 5. Average and spot uranium prices in 2003 dollars[8]

[8] Frank von Hipple, *op cit*

Now, it may be that 50 years ago with less knowledge about the availability it might have seemed a good bet to reprocess.  But that bet has failed, and it has made no sense for Rokkasho to be built and it makes even less sense from the point of view of saving money and uranium for the U.S. to go into reprocessing.

**Figure 6. France's spent-fuel reprocessing complex on La Hague** in northern France. Its plutonium fuel fabrication facility is in southern France, requiring regular long-distance truck shipments of separated plutonium.[49]

Reprocessing has other problems. I have visited both THORP at Sellafield, England, and the COGEMA plant at La Hague, France. During the reprocessing (and for decades after in the case of Sellafield) much of the radioactivity instead of being locked in spent fuel elements has been made freely available in enormous tanks of concentrated CS-137, that must be actively cooled (via a triply redundant cooling system) if it is not to evaporate and spread its radioactivity over the countryside. GNEP proposes not only to separate the minor actinides and to burn them in the ABR fast-neutron reactors, but to separate out the 30-year half-life strontium-90 and cesium-137 (each has a 30-year half-life) and to store them for hundreds of years above ground (one hopes not in the form of liquid) until they decay and can be entombed in the repository. But these radionuclides have the preponderance of the decay heat, and they must either be actively cooled or contained in passively cooled shielding casks essentially identical with those that would be required for the spent fuel from which the Cs and Sr were obtained.

The rather complicated considerations of benefit of minor-actinide removal and Cs-Sr removal on repository capacity, to remain below the boiling point of water in the “dry environment” of Yucca Mountain, are shown in the figure.

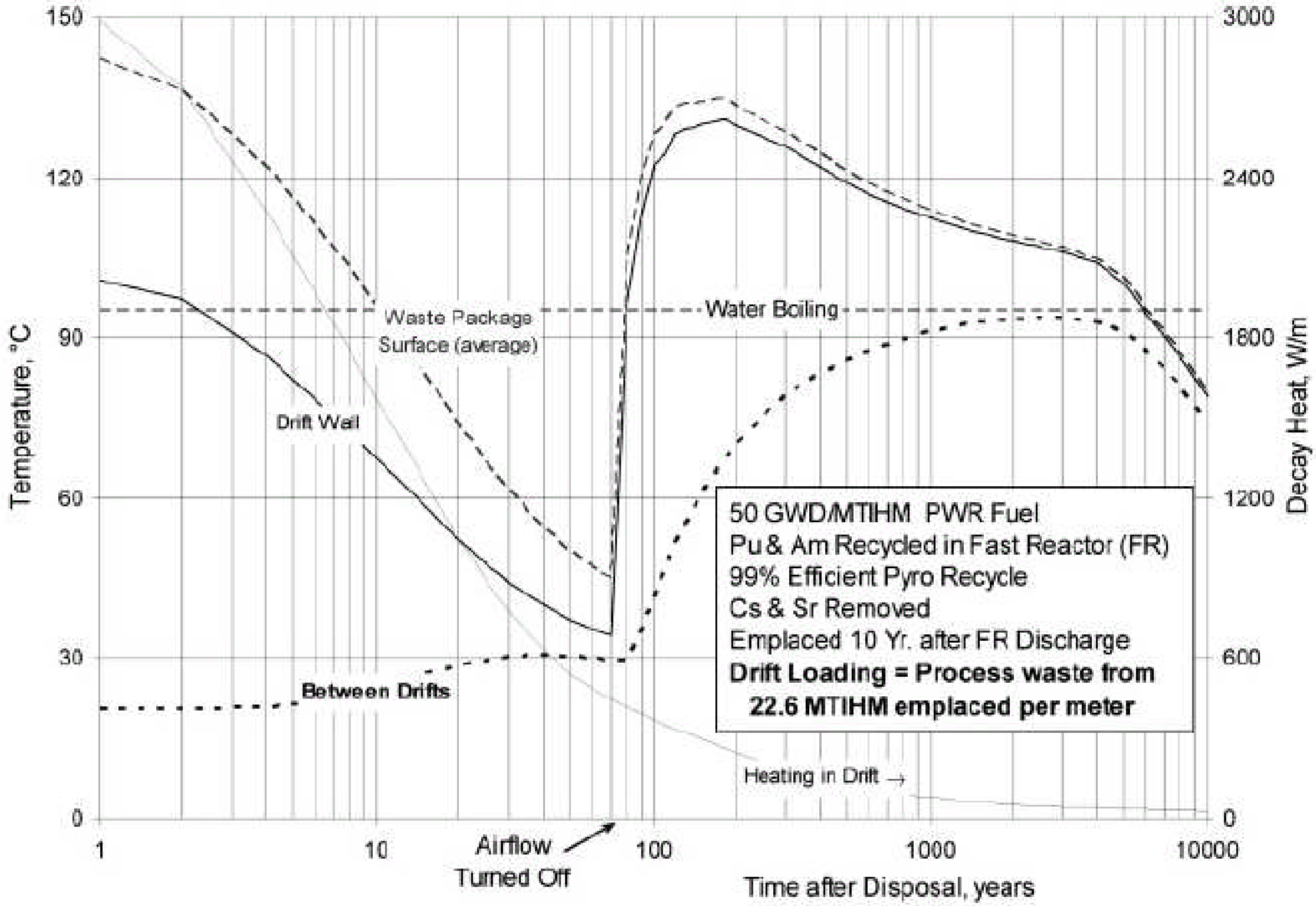


Fig. 6. Transient thermal response of a repository at Yucca Mountain with removal of plutonium, americium, cesium, and strontium from spent PWR fuel, recycling plutonium and americium in a fast reactor, with increased drift loading.

Fig. 6. Transient thermal response of YM respository[9]

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[9] "Separations and Transmutation Criteria to Improve Utilization of a Geologic Repository," by R.A. Wigeland, T.H. Bauer, T.H. Fanning, and E.E. Morris, Nuclear Technology, vol. 154, pp. 95-106, (April 2006).

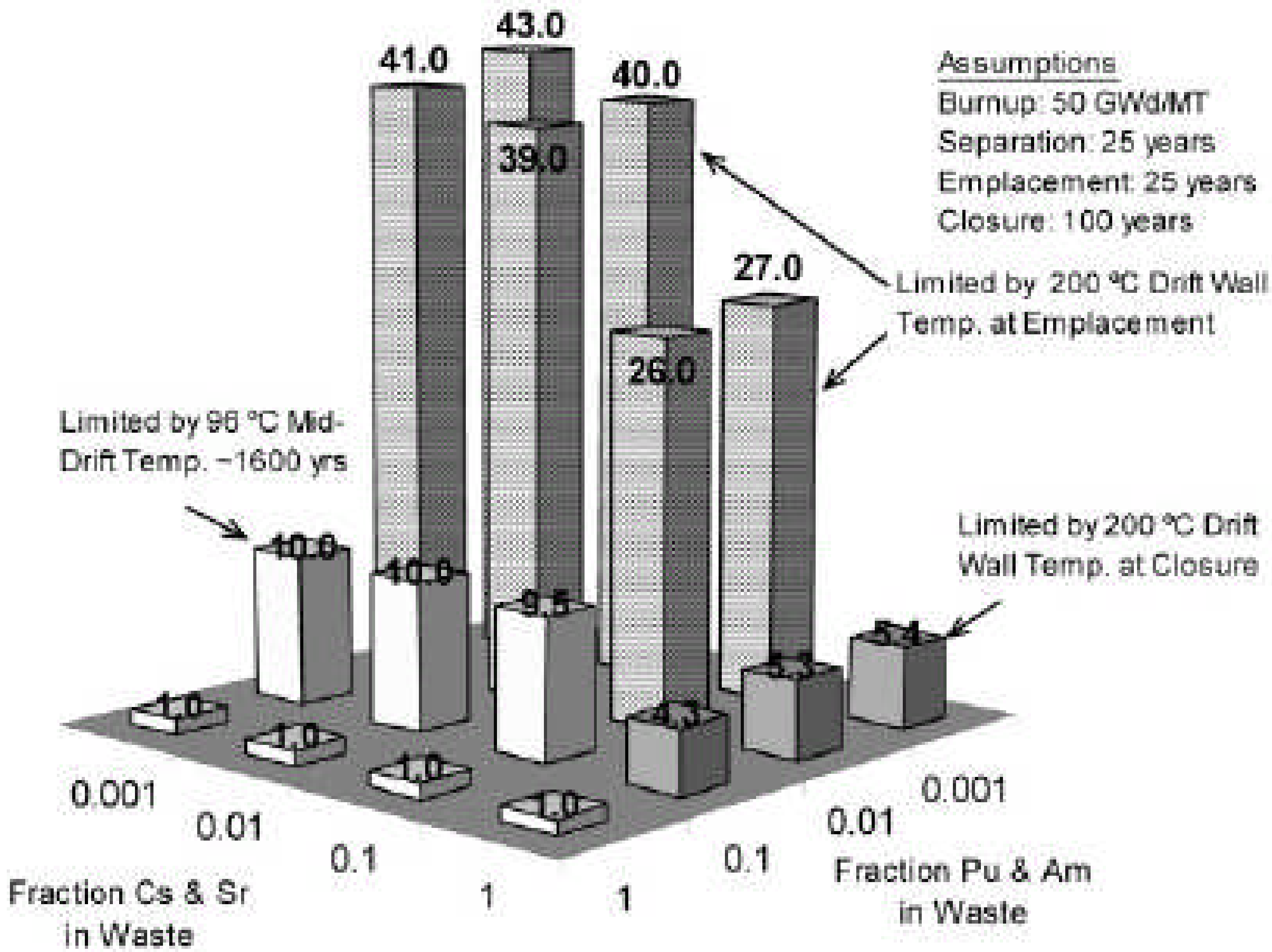


Fig. 7. Potential repository drift loading increase as a function of separation efficiency for plutonium, americium, cesium, and strontium.

Fig. 7. Potential repository drift loading increase.[10]

[10] R.A. Wigeland *et al*, *op cit.*

The reprocessing world adds additional potential hazards. The THORP plant at Sellafield was shut down in April 2005 with the discovery that 25 tons of spent fuel (a full reactor-year's worth) dissolved in 83 cubic meters of acid had leaked over a period of months into a stainless-steel-lined concrete enclosure. THORP will have been closed for at least two years, sacrificing an income stream that at 750 tons per year of spent fuel and an estimated $1000/kg reprocessing fee would amount to some $1.5 billion.

A current EPRI-INL paper provides a sobering assessment both of the prospects for the reprocessing approach and of its necessity:[11]

> "In addition, reprocessing plants are expensive and not attractive to commercial financing in the context of the U.S. economy.  Thus, the cost increment for reprocessing (i.e., the incremental cost above the cost of repository disposal) will be subsidized initially by the federal government. Although the estimate above does not include repository costs, it is expected that reprocessing will remain more expensive than storage (centralized above-ground

[11] "The Nuclear Energy Development Agenda: A Consensus Strategy for U.S. Government and Industry."

plus geologic repository) for the foreseeable future. Projections of major savings in Yucca Mountain repository costs as a result of reprocessing are highly speculative at best. On the other hand, the increased revenues to the Nuclear Waste Fund from an expanding fleet of new reactors will eventually help defray the costs of operating closed fuel cycle facilities.

I add here also material from the EPRI report: of May 2006, "Program on Technology Innovation: Room at the Mountain – Analysis of the Maximum Disposal Capacity for Commercial Spent Nuclear Fuel in a Yucca Mountain Repository. EPRI, Palo

Alto, CA: 2006. 1013523." There we read, "EPRI is confident that at least four times this legislative limit (~260,000 MTU) can be emplaced in the Yucca Mountain system..." And EPRI believes that with additional site characterization this minimum factor of 4 could well be a factor 9.

*"It is important to note that despite the extended timetable for introducing reprocessing in the U.S. (due to R&D prerequisites to satisfy cost and nonproliferation objectives, policy considerations, etc.), that a single expanded-capacity spent fuel repository at Yucca Mountain is adequate to meet*

*U.S. needs, and that construction of a second repository is not required under this timetable.*

*"If, however, reprocessing is implemented on an accelerated schedule before it is economic to do so based on fuel costs, then the federal government will need to bear a much larger cost. As discussed in Appendices B and D, the optimum scenarios for transitioning nuclear energy to a closed fuel cycle in the U.S. context requires us to focus the R&D on those technologies that would enable a transition to cost-effective and proliferation resistant "full actinide recycle" mode with fast reactors that would eventually replace light water reactors. This path is*

*preferred over one that maintains for decades a "thermal recycle" mode using MOX fuel in light water reactors, because the high costs and extra waste streams associated with this latter path do not provide commensurate benefits in terms of either non-proliferation or spent fuel management costs*."

In what world does the drive for reprocessing make sense? In the long-sought world of fast-neutron breeder reactors which differ from the fast-neutron ABRs in that the breeders produce at least one plutonium atom for each transuranic atom destroyed—a conversion ratio—*CR*—of 1.0 or more; in contrast, that ABR is desired that has a CR of 0.0, which could only be achieved with fuel containing no uranium. The CR goal for ABR is 0.25, although previous analyses for a very comprehensive 1996 National Academy study[12] quotes a General Electric judgment that a CR of 0.65 is the minimum practical. The difference is that the number of million-kWe ABRs to burn up the plutonium from 100 LWRs is proportional to (1/(1-CR)), which is more than doubled with the reactor of CR=0.65. Since the fast-neutron reactor is expected to be more costly than the LWR, this has serious cost implications for the GNEP approach.

[12] Nuclear Wastes: Technologies for Separations and Transmutation," by the Committee on Separations Technology and Transmutation Systems, ("STAP" for short), National Research Council, National Academy Press, Washington, DC (1996). (http://books.nap.edu//books/0309052262/html)

It is clear that some GNEP supporters have mixed feelings about the central pillar of GNEP—the ABR fleet.  For instance, at an October 17, 2006 meeting, in presenting his very detailed technical paper, "Technologies for Advanced Fuel Cycles," Finck commented that he did not favor the Compact Core sodium-cooled fast reactor (pp.17-18)

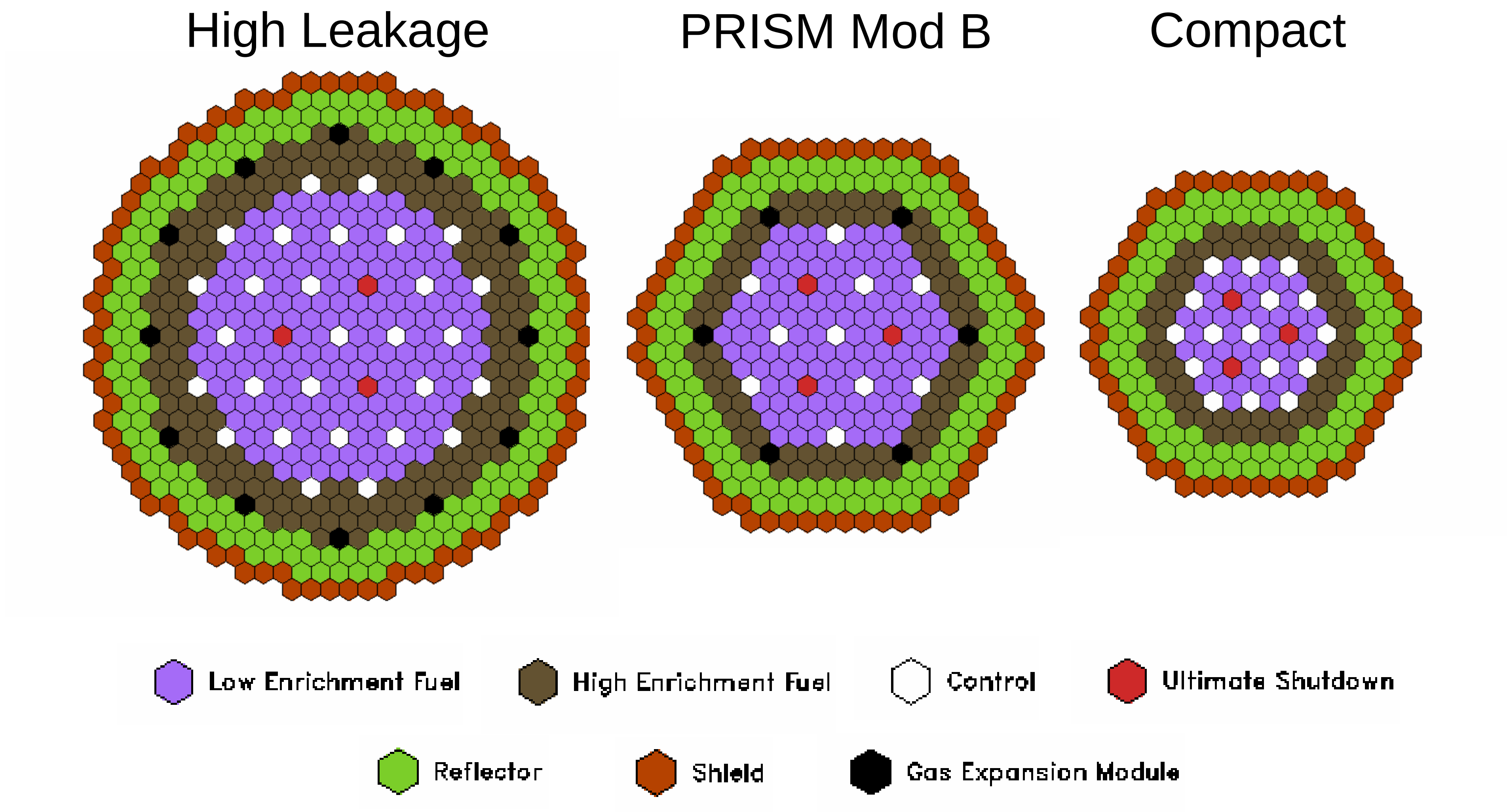


Fig. 8. Core configurations for several ABR candidates[13]

[13] Phillip J. Finck, *op cit.*.

| | PRISM Mod B | High Leakage | | Compact Core | |
|---|---|---|---|---|---|
| **Conversion Ratio** | **0.8** | **0.5** | **0.0** | **0.5** | **0.0** |
| **Capacity Factor** | **0.86** | **0.83** | **0.83** | **0.82** | **0.82** |
| **Annual Generation (TWh/yr)** | **14.07** | **13.60** | **13.60** | **13.47** | **13.47** |
| **Total Capital Cost ($/kWe)** | **1,554** | **1,626** | **1,626** | **1,536** | **1,541** |
| **Total Levelized Cost (mills/kWhr)** | **40.4** | **47.7** | **47.7** | **39.6** | **39.7** |
| Capital | 20.0 | 21.7 | 21.7 | 20.7 | 20.7 |
| O&M | 7.0 | 7.3 | 7.3 | 7.5 | 7.5 |
| Fuel | 12.4 | 17.7 | 17.7 | 10.4 | 10.4 |
| Decommission | 1.0 | 1.1 | 1.1 | 1.0 | 1.0 |

- Compact low conversion design COE is similar to reference system
  - High leakage configuration increases cost by 20%
- Fuel cost differences are the most significant discriminator
- Capacity factor penalizes Capital and O&M components for burners
- Details are given in the AFCI report ANL-AFCI-118

with a CR=0.5 and an electricity production cost of 39.7 mills/kwh (a mill is 0.1 cent) over a “high-leakage” reactor with the same CR and a Total Levelized Cost of 47.7 mills/kwh. Finck’s reason is that the compact-core fast reactor could not be readily converted to a breeder reactor by replacing the inert (steel) “blanket” by depleted-uranium fuel elements. Given that the cost paid by US reactor operators for waste disposal is 1mill/kwh, to accept one fast reactor design over another at 10 times the non-reprocessing waste disposal cost is a phenomenal penalty to be paid for a contingency never discussed in the GNEP literature—that we should deploy sodium-cooled fast reactors that can readily be converted into breeder reactors under the guise of reactors that burn up as much plutonium as possible rather then regenerating it.

In a recent presentation[14], Dr. Finck[15] clearly stated that with "limited recycle" of Pu as practiced in France, the process acted like a "delay line" in delaying the need to put material into the mined geological repository for 15-20 years.  This is not the benefit on which the program was sold to the French people or to the principal customers—Japan and Germany.  It is far cheaper and safer to use dry-cask storage

[14] "Plutonium Reprocessing and the Future of Nuclear Power" AAAS symposium, San Francisco, February 17, 2007.
[15] Now associate director for Nuclear Programs at DOE's Idaho National Laaboratory, essentially a technical leader in the GNEP program.

**Figure 9. Dry cask storage of spent fuel.** Two casks typically contain the equivalent of a year's spent fuel discharges from a 1000 MWe nuclear power plant. Comparison of the simplicity of interim spent fuel storage with the complexity of the huge reprocessing complex shown in Figure 6 makes it easier to understand the relatively low cost of interim storage.[87]

Fig. 9. Dry-cask storage of spent fuel (Yankee site)[16]

[16] Frank von Hippel, *op cit*

In a journal article of January 2007[17] Robert Dautray, who built the first French fast reactor and was head of the CEA[18], writes,

*Together with the important launching of EPR[19] reactors (and of considerable importance for safety and radioprotection), the next two decades should in priority finalize the back end of the fuel cycle of the thermal neutron power reactors, …, with a final disposal into a underground geological repository (for the radioactive products generated in the past and future nuclear activity of this country). It is an* ***illusion*** *to count on a notable reduction of the fission products by using* ***fast neutron reactors****: to face the long term world requirements,* ***their essential task****, necessary before the end of the century,* ***will be to make energy from fission competitive with that of coal*** *or eventually with other types of energy from fusion.[emphasis added]*

Dautray specifically rejects the concept of the Advanced Burner Reactor, but urges the disposal of fission products and spent fuel into the mined geologic repository and the development of fast-neutron breeders that (if they) can be cheaper than coal.

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[17] R. Dautray and J. Friedel, "Energy: towards nuclear breeder installations before the end of this century?" C. R. Mecanique 335 (2007) 61–74.
[18] Commissariat à l'énergie atomique
[19] Evolutionary Power Reactor (formerly the European Pressurized Reactor).

As for myself, I favor the deployment of breeder reactors and their mandatory reprocessing and recycle of plutonium, but only when the cost and safety of the fast reactor system is demonstrably better than that of reactors with the once-through cycle. In the future, once-through is not limited to LWRs but could include the micro-encapsulated fuel pioneered by General Atomics and now under development in a joint program with Russia as a modular high-temperature gas turbine reactor, and in South Africa as a *pebble-bed* reactor. In 1982 I testified against the Clinch-River breeder reactor program because it had no chance of demonstrating anything other than that the concept was a high-cost approach.

Similarly I testified in 1970 against the US Government-funded commercial supersonic transport program—*SST*—and was vilified by program supporters, including the US airlines which had had their arms twisted to provide moral support for the SST program. The USG had testified that if the US did not develop the Mach-3 SST to compete with the British-French Concorde Mach-2 SST, US airlines would end up buying 500 Concorde aircraft. In fact, only 16 Concorde aircraft were built and transferred to the national airlines, of which only 9 ever flew in commercial service. Ten years later, the SST contractors, Boeing and General Electric, thanked me for helping to terminate the program in its early stages.

The DOE *process* for obtaining approval for GNEP is defective; DOE does not have the systems analysis tools to design and judge such a program, despite its commitment to the Congress to develop them.  Nor does it freely provide information for independent analysis.  I have long urged my DOE colleagues, including Vic Reis, a moving spirit of the program, to create a DOE website where government-financed papers would be posted, as I and Frank von Hippel post our own analyses. The response has been that the existing technical website operated by Sandia National Laboratories and available only to government and selected contractors cannot be influenced by DOE headquarters.

Einstein’s words, "The right to search for truth implies also a duty; one must not conceal any part of what one has recognized to be true" are engraved in stone on the Keck Center of The National Academies in Washington, DC. It would be helpful if the DOE took them to heart. Failing to do so is likely to inflict serious damage on the US nuclear industry.

# CONCLUSIONS RE GNEP

- "Proliferation resistant" reprocessing seems to be anything that the US decides to do, and thus will increase rather than reduce proliferation hazards worldwide.
- A US sodium-cooled fast reactor is another me-too; we should use foreign fast reactors—especially the BN-600—for testing of fuels.
- GNEP is unresponsive and secretive. They ignore technical facts and provide none of their own.
- Cartridge reactors and secure fuel cycle will be a competition unless the US strongly subsidizes the

world's nuclear power program, which is undesirable and unacceptable under the WTO.

- Missing from the DOE program is an urgent effort to determine the "uranium supply curve"—cost per kg of uranium (both from terrestrial resources and from ocean uranium) vs. millions of tons of uranium extracted.
- Missing also is leadership in an initiative to permit competitive, commercial, mined geologic repositories to accept spent fuel from any source, or packaged nuclear waste, with repositories and waste forms alike, in the US and abroad, regulated by IAEA.

- With its focus on reprocessing of US reactor fuel GNEP is so flawed that it should be terminated
  - The international *policy* aspects of the secure fuel cycle (without committing to reprocessing) should be handled by State and DOE.
  - Other aspects should be handled by AFCI—the Advanced Fuel Cycle Initiative.
  - I personally favor a major exploration of a fast breeder reactor and accompanying fuel form and reprocessing of the breeder fuel, *when and only when* it can be responsibly shown to be safer, cheaper, and as proliferation resistant as current US power reactors.