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A PERSPECTIVE ON THE US NUCLEAR FUEL CYCLE

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ABSTRACT

There has been a resurgence of interest in the possibility of processing the US spent nuclear fuel, instead of burying it in a geologic repository. Accordingly, key topical findings from three relevant EPRI evaluations made in the 1990-1995 timeframe are recapped and updated to accommodate a few developments over the subsequent ten years. Views recently expressed by other US entities are discussed. Processing aspects thereby addressed include effects on waste disposal and on geologic repository capacity, impacts on the economics of the nuclear fuel cycle and of the overall nuclear power scenario, alternative dispositions of the plutonium separated by the processing, impacts on the structure of the perceived weapons proliferation risk, and challenges for the immediate future and for the current half-century.

Currently, there is a statutory limit of 70,000 metric tons on the amount of nuclear waste materials that can be accepted at Yucca Mountain. The Environmental Impact Statement (EIS) for the project analyzed emplacement of up to 120,000 metric tons of nuclear waste products in the repository. Additional scientific analyses suggest significantly higher capacity could be achieved with changes in the repository configuration that use only geology that has already been characterized and do not deviate from existing design parameters. Conservatively assuming the repository capacity postulated in the EIS, the need date for a second repository is essentially deferrable until that determined by a potential new nuclear plant deployment program. A further increase in technical capacity of the first repository (and further and extensive delay to the need date for a second repository) is potentially achievable by processing the spent fuel to remove the plutonium (and at least the americium too), provided the plutonium and the americium are then comprehensively burnt. The burning of some of the isotopes involved would need fast reactors (discounting for now a small possibility that one of several recently postulated alternatives will prove superior overall). However, adoption of processing would carry a substantial cost burden and reliability of the few demonstration fast reactors built to-date has been poor. Trends and developments could remove these obstacles to the processing scenario, possibly before major decisions on a second repository become necessary, which need not be until mid-century at the earliest. Pending the outcomes of these long-term trends and developments, economics and reliability encourage us to stay with non-processing for the near term at least.

Besides completing the Yucca Mountain program, the two biggest and inter-related fuel-cycle needs today are for a nationwide consensus on which processing technology offers the optimum mix of economic competitiveness and proliferation resistance and for a sustained effort to negotiate greater international cooperation and safeguards. Equally likely to control the readiness schedule is development/demonstration of an acceptable, reliable and affordable fast reactor.

SCOPE

This brief review:
- recaps key topical findings from three EPRI evaluations made in the 1990-1995 timeframe
- incorporates a few updates resulting from inputs during the subsequent ten years
- discusses some relevant views recently expressed (2003-5) by other US entities.

BACKGROUND

Circa 1990, a new justification, a waste disposal benefit, was promulgated for the US processing-plus-fast-reactors development program. The original justification, increased nuclear fuel resources, had been in decline as nuclear plant deployment dried up and more uranium ore was found. The waste disposal benefit was claimed by some to include elimination of the need for a geologic repository. EPRI therefore evaluated the waste disposal benefit (Rodwell et al., 1991).

After staff review, the US Department of Energy expressed acceptance of EPRI's findings and requested a small supplemental effort applying the accrued data to identifying R&D that might validate a way of substantially delaying the need date for a second repository (Rodwell et al., 1992).

Five years later, EPRI made a more detailed and broader-scope evaluation (addressing MOX-LWRs as well as fast reactors) of just the cost impacts (Burch et al., 1996).

KEY FINDINGS, RECENT RELEVANT INPUTS, AND DISCUSSION

Waste Disposal Findings

The waste packages that would result from removal of the actinides from spent fuel would not qualify the residue for near-surface instead of geologic disposal (first EPRI evaluation - Rodwell et al., 1991). Even if further development of partitioning technology achieved a tenfold improvement in transuranic separation efficiencies, none of the waste packages would be downgraded from geologic to near-surface disposal. Their enclosed residual transuranics, extremely long-life fission products, extremely long-life activation species and medium-life, high-activity fission products would still be too high. This finding applies both to aqueous processing and to pyrochemical processing.

On the repository's retention of the unprocessed spent fuel's isotopes, contemporaneous analyses were showing that dissolution rates plus travel times would provide large margins over very conservative regulated isotope leak rates (first EPRI evaluation - Rodwell et al., 1991).

The removal (and destruction) of large fractions of the transuranics (plutonium plus the minor transuranics) from the spent fuel would reduce the repository-bound waste's heat output and thereby increase the GW-years of power generation that a repository could support (first EPRI evaluation - Rodwell et al., 1991). For example, if the bulk of the transuranics are removed from 25-year old spent fuel, the heat release at that point in the spent fuel's aging is reduced by about 25%. (The 25-year old age was picked for this example because the spent fuel will de facto have an average age of at least a quarter of a century by the time it is deposited in the repository.)

An alternative or additional way to reduce the heat output and thereby increase a repository's capacity is to delay further the uncooled emplacement of either the spent fuel or the processing waste packages that contain the cesium and strontium (second EPRI evaluation - Rodwell et al., 1992). Extending the above example, if the spent fuel or the waste packages are stored external to the repository until fifty years instead of twenty-five years have elapsed, the heat release rate is about 65% (for the spent fuel) or 40% (for the waste packages) of that of the 25-year old spent fuel. Continuing delay accrues further heat release reduction for the waste packages, but beyond fifty years accrues minimal additional benefit for the spent fuel, because the transuranics then keep the heat release up.

Expressing these percentages as repository capacity increments involves introducing heat accumulation as opposed to simply heat rate, and impacts from the assumed disposition of the transuranics removed in the processing option, and addressing differing locations within the repository (all of which regrettably work in the direction of somewhat reducing the value of delaying the uncooled emplacement). This is too detailed for this brief review, but a few results emerge below.

Recent Waste Disposal Inputs and Discussion

A recent compilation of actual and projected French processing experience (Andra, 2005) indicates that the volume of process waste that needs packaging and eventual disposal in a geologic repository is very similar to the volume of spent fuel that the process waste was derived from (~0.5 m^3/MTHM).

The potential benefit, identified in the 1990-1995 evaluations, from delaying uncooled emplacement of the spent fuel, has since been de-facto accrued, not by deliberate further delay to emplacement of the spent fuel, but by incorporating a tunnel cooling system, which will operate beyond this 50-year spent fuel age. At the time of the 1990-1995 evaluations, the technical capacity (having no tunnel cooling) was expected to be around 100,000 metric tons. Today, a higher capacity is alluded to in recent literature. Thus in a recent testimony from Matthew Bunn (Bunn, 2005a):
"... it is possible that even if all existing reactors receive license extensions allowing them to operate for 60 years, Yucca Mountain will be able to hold all the spent fuel they will generate in their lifetimes, without reprocessing."
And from Phillip Finck (Finck, 2005):
"The ultimate technical capacity of Yucca Mountain is expected to be around 120,000 metric tons, using the current understanding of the Yucca Mountain site geologic and hydrologic characteristics. This limit will be reached by including the spent fuel from current reactors operating over their lifetime."

If Yucca Mountain accommodates the current plants' lifetime spent fuel output, the need date for a second repository is deferred until that determined by a potential new nuclear plant deployment program. If that program's spent fuel is not deposited until it is fifty years old or so (the above alternative way to accrue the heat reduction benefit), then the second repository will not need to open till circa 2070 (and probably later), and major decisions on that repository will not be necessary till mid-century. This alternative requires more interim storage capacity, but no tunnel cooling system. These dates apply even if the second repository needs to accommodate the tail end of the existing program’s spent fuel.

Additional scientific analyses recently completed (Apted, 2006; Kessler, 2006) suggest that even significantly higher capacity could be achieved with changes in the repository configuration that use only geology that has already been characterized and do not deviate from existing design parameters. In this case, a single expanded capacity spent fuel repository at Yucca Mountain would be adequate to meet U.S. needs for the foreseeable future.

Economics Findings

Turning to the above option that could (in some scenarios but not all) accrue a much bigger repository capacity increase, i.e., removal of the transuranics, the costs of the various fuel cycle elements are discouraging for scenarios involving processing (third EPRI evaluation - Burch et al., 1996). However, continuing operation of existing nuclear plants and deployment of additional plants will deplete the most accessible, highest-grade uranium ores and cause the ore cost to rise. Because processing fuel cycles use less uranium ore, their cost handicaps versus not processing will decrease. But the economic trade-off between not processing and processing is not very sensitive to uranium ore cost, so it will take a big increase in ore cost to cancel processing's handicap. Uranium Redbook (OECD, 2001) data indicate that it will take a major deployment of additional LWRs several decades to cause that big an ore cost increase.

Explaining the above parenthetical note that not all processing scenarios would accrue a much bigger repository capacity increase, the primary source of plutonium's long term heat release is the 238, 240 and 241 isotopes (the 241 mainly via its daughter Am-241). These are consumed in fast reactors, but only to a minor degree in MOX-LWRs, which continue to generate more. To accrue the much bigger repository capacity increase, the scenario must include some machines that consume these isotopes, the fast reactor being the salient example of such machines. Unfortunately, the demonstration fast reactors built to-date have mostly been unreliable, which aggravates the above finding that processing scenarios are economically unattractive.

Synergism

A modest synergism emerges. If, for repository considerations, a new deployment program's spent fuel is not deposited till it is say fifty years old, and thence major decisions on a second repository are not due till mid-century, several decades are available for seeing where the uranium ore cost goes and where processing's cost handicap goes, for determining whether fast reactors can be made reliable, and for updating an assessment on whether and when to adopt a processing scenario. All the existing spent fuel will still, of course, be accessible for processing should that be the decision.

Political/Public Acceptance

A non-technical aspect that was flagged but not discussed in the '90-'95 EPRI work is political/public acceptance. This has proved to be a big obstacle to the Yucca Mountain repository and understandably drives the recent enthusiasm for a processing scenario that offers a long deferral of the need date for a second repository. However, as noted above, major decisions on a second repository are not necessary till mid-century anyway. Also, processing will need political/public acceptance of a perceived health risk near term instead of many thousands of years hence and political/public acceptance of a differently-structured perceived near-term weapons proliferation risk (as returned to below).

Recent Economics Inputs and Discussion

The essence of the above overall finding on processing fuel cycles (modest waste disposal benefit at substantial but slowly declining cost) has been echoed to varying extents in recent reports from other entities. Thus MIT (Beckjord et al, 2003):

a "We do not believe that a convincing case can be made on the basis of waste management considerations alone that the benefits of partitioning and transmutation will outweigh the attendant ... economic costs. ... For our fundamental conclusion to change, ... not only would the expected long term risks from geologic repositories have to be significantly higher than those indicated in current assessments, but the incremental costs [of partitioning and transmutation] ... would have to be greatly reduced relative to current expectations and experience."

b "We believe that the world-wide supply of uranium ore is sufficient to fuel the deployment of 1000 reactors [1GW, once-through] over the next half century and to maintain this level of deployment over a 40 year lifetime of this fleet."

The global deployment scenario postulated in this quote would consume less ore than that estimated by the Uranium Redbook to be accessible at less than ~\$40/lbU_3O_8, backed up by a similar amount estimated or speculated to be accessible at less than twice that cost. The next few years should reveal whether the recent rise to over \$40/lbU_3O_8 (cost to the customer, not to the miner) indicates that this Redbook estimate is inaccurate or whether the recent rise reflects that forecast, a decade or two ago, to occur when the market has eliminated the over-capacity/production of the mines established circa 1970 when global nuclear plant deployment was very aggressive.

c "We considered reprocessing and one-pass fuel recycle with current technology, and found the fuel cost, including waste storage and disposal charges, to be about 4.5 times the fuel cost of the once-through cycle."

This is a surprisingly high ratio. Its derivation is outlined in the report's appendix, which reveals that the ratio applies just to the fuel that is plutonium enriched, e.g., to MOX fuel assemblies within a core of otherwise UOX assemblies, or to all-MOX reactors within a fleet of otherwise UOX reactors. In the model that the appendix analyses, the MOX fuel is only ~16% of the total, so the cost ratio for the overall MOX/UOX complex is ~1.5, not 4.5. This is still substantial (an increment of 2.8 mill/kWh), but not as devastating.

A caution; these findings need to be kept in context. For the scenario in which the spent fuel from the existing fleet of US plants is processed and enough all-MOX plants to use the separated plutonium are deployed (say 18 GW), such plants would carry the initial (larger) interpretation of the fuel cycle cost penalty.

Then the Belfer Center (Bunn et al., 2005b):

a "At a reprocessing price of \$1,000 per kilogram of heavy metal ... reprocessing and recycling plutonium in existing light-water reactors (LWRs) will be more expensive than direct disposal of spent fuel until the uranium price reaches over \$360 per kilogram of uranium ..."

This assumed processing cost of \$1,000 per kilogram is a little higher than that indicated by the updated EPRI evaluation (\$800/Kg), which derives a nominal break-even uranium cost of \$300/kgU, reasonably close to the Belfer Center conclusion.

The assumed cost of processing dominates such trade-offs, and therein lies much uncertainty. The two biggest contributors to the uncertainty are 1) how much will European experience and continuing R&D reduce costs below those incurred at the existing large European processing plants, and 2) who will own the US processing plants and thence what discount rate will apply to these high capital cost facilities. In any case, the break-even uranium cost will be well above the ~\$40/lbU_3O_8 (\$100-110/kgU) that the Uranium Redbook indicates should (but not necessarily will) cover more than enough uranium to fuel the 1,000-GW deployment scenario postulated in the MIT report (see above).

Related, from the separate testimony of Matthew Bunn (Bunn et al., 2005a) is:
"World resources of uranium likely to be economically recoverable in future decades at prices far below the price at which reprocessing would be economic are sufficient to fuel a growing global nuclear enterprise for many decades, relying on direct disposal without recycling."

b "At a uranium price of \$40/kgU ... recycling at a reprocessing price of \$1,000/kgHM would increase the cost of nuclear electricity by 1.3 mill/kWh."

This compares with the 2.8 mills/kWh derived by the MIT report (see above), with the same assumption for the big-ticket item (processing cost). The updated EPRI evaluation indicates 1 mill/kWh, again somewhat lower than the Belfer Center estimate. (In case a reminder is needed, this cost increment applies, as the quote says, to the cost of nuclear electricity, i.e., to the overall MOX/UOX complex, not just to the MOX portion.)

c "Even if the capital cost of new FRs [fast reactors] could be reduced to equal that of new LWRs, recycling in FRs would not be economic until the uranium price reached some \$140/kgU."
"... the extra electricity cost would be over 2 mills/kWh"

For equal FR and LWR plant capital costs, the updated EPRI evaluation indicates break-even at a nominal \$200/KgU, and today's extra electricity cost would be 2.5 mill/kWh. Thus, for the FR, the EPRI evaluation is somewhat more, rather than less, discouraging than is the Belfer Center estimate. This is mainly due to differences in two assumptions: based on a UK publication, EPRI expects processing spent FR fuel will cost much more than will processing an equal weight of spent LWR fuel, and the EPRI evaluation represents an exactly self-supporting FR (unity breeding ratio) whereas the Belfer Center result represents a breeder.

Nothing should be drawn from this result that the break-even uranium cost for the FR is likely to be lower than that for the MOX-LWR. This indication results from the major assumption that the FR will have the same capital cost as the LWR, Because of the dominance of capital cost in nuclear power economics, a credible excess in the capital cost for the FR would close (perhaps reverse) this difference in break-even uranium costs. Both the Belfer Center report and the EPRI evaluation suggest that the FR costing more than the LWR is more likely than the reverse.

On the other hand, a break-even uranium cost for the MOX-LWR as low as that for the FR would have little meaning, because if the uranium cost rises this much it will presumably be on a roll. Adoption of MOX-LWR would dampen but not stop it, because MOX-LWRs wouldn't reduce the long-term consumption of uranium ore much; whereas a switch to FRs would stop the rise, because FRs would not require any more uranium to be mined.

At that time, a mix of MOX-LWRs and FRs may prove appropriate, at least for a while. If and when FRs are deployed to cap a rising ore cost, they will need only a fraction of the plutonium that will have been generated (third EPRI evaluation - Burch et al., 1996). One of several options for the rest of the plutonium is MOX-LWR, which presumably will be rendered close to economic by the ore cost rise that triggers the FR deployment. (To maximize the repository benefit, it will be necessary to recycle the spent MOX-LWR fuel's transuranics to the FRs, to burn the isotopes that the MOX-LWRs cannot burn.)

Finally, both the Belfer Center report and the '95 EPRI report point out that an enormous uranium resource in sea water may be tappable at less than these break-even uranium costs, so it is within the range of possible outcomes that MOX-LWR and/or FR deployment may never be free of a residual cost penalty. Although it is a great challenge to achieve the enormous concentrations necessary to realize uranium densities useful for nuclear fuel, this potential sea water option merits further long-term R&D.

General Fast Reactors Findings

Expanding on a point immediately above, if and when fast reactor deployment does become appropriate, extant LWRs at that time are likely to be producing plutonium at a rate that will support the fast reactor deployment. Plutonium created prior to that time will not be needed. Rather than fast reactors needing this plutonium, it is the plutonium that needs fast reactors (or some less-obvious actinide burner), if the current desire to minimize the number of repositories is sustained and is to be satisfied.

Long-term fast reactor and processing development is encouraged, to protect future nuclear power from an eventual diminishing supply of U-235 and large uranium ore cost increase (all three EPRI evaluations - Rodwell et al., 1991, Rodwell et al., 1992, Burch et al., 1996). Development tasks towards defining the most cost-effective and reliable of the acceptable fast reactor and fuel cycle technologies remain important. It was and remains implicit in this finding that we do not yet know which processing/fast-reactor technology combination is the best choice to take through as far as a demonstration.

Proliferation

Proliferation considerations could affect to-process or not-to-process decisions. As the scopes of the '90-'95 EPRI work were economics and waste disposal benefits, the proliferation issue was merely flagged and not discussed. Today the issue is more topical so an EPRI view needs to be developed. The following is an initial attempt.

EPRI has not had access to the classified information that would allow EPRI to make its own evaluation from scratch, so it has had to build its evaluation on such weapons-expert opinions as they get released. These vary from the opinion that a bomb can in theory (and therefore actually might) be makeable from any plutonium isotopic mix to the opinion that the 238, 240 and 241 isotope contents make impractical a bomb with plutonium from spent fuel taken to LWR discharge burnups (or indeed much lower burnups). (A good introduction to the issue is Pellaud, 2002.) With this degree of uncertainty, it is understandable that the Spent Fuel Standard, which emerged for disposition of excess weapons plutonium, reflects the additional protection/deterrent provided by the very hazardous radiation level of unprocessed commercial spent fuel.

A topical question is can we visualize a separations technology for commercial spent fuel that, although inevitably giving up a good deal of this radiation deterrent, would retain adequate proliferation resistance? A key concern in addressing this question is a vision that US adoption of any separations technology will encourage global use. Then there will be multiple non-US processing locations, each with the potential either for adjusting the process to produce clean reactor-grade plutonium and/or for diversion of no-longer-Spent-Fuel-Standard-protected reactor-grade plutonium to a small undetectable aqueous clean-up unit.

For example, a major fraction of the US processing technology development effort over the last twenty-five years has been on a pyro technology that leaves some of the minor actinides and fission products with the plutonium, thereby retaining some of the radiation deterrent. But it will be very difficult to achieve a consensus that such a mix will not be too hazardous to use in a fuel fabrication plant and then in reactor fuel handling yet be too hazardous to divert to a small aqueous clean-up unit. There will also be the question whether a rogue operator of a pyroprocess could adjust it to produce clean plutonium. Thus claims that pyro technology is much more proliferation resistant than aqueous technology are not persuasive. An EPRI review of recent technical literature has not disclosed any new silver-bullet technology; indeed it is difficult to imagine that there could be one.

The recent Bunn testimony (Bunn, 2005a) testimony reflects this concern:
"... proposed new approaches are not as proliferation resistant as they should be ..."
"... the plutonium-bearing materials that would be separated in either the UREX+ process or by pyroprocessing would not be radioactive enough to meet international standards for being “self-protecting” against possible theft."
"... if these technologies were deployed widely in the developing world, where most of the future growth in electricity demand will be, this would contribute to potential proliferating states building up expertise, real world experience, and facilities that could be readily turned to support a weapons program."

On the other hand, contemporaneous

testimony from Roger Hagengruber (Hagengruber, 2005) allows the possibility of processing proving acceptable:

"The ultimate assessment should not be based on whether it is theoretically possible to make a weapon from the waste. A meaningful assessment must evaluate practical factors associated with making a weapon: the level of technical sophistication, the willingness to assume risk, the financial resources available, and the likelihood of success."

It is inferred here that Hagengruber is alluding primarily to the above practical difficulties deriving from the 238, 240 and 241 isotopes.

If something additional to the practical difficulties deriving from the 238, 240 and 241 isotopes is truly needed, there is some possibility that the locations of the less-than-perfect processing scenario facilities could be controlled adequately via international agreement plus adequate safeguards at the permitted locations. However, experience to-date is not very encouraging. If doing a particular thing is in a nation's interests, such carrots and sticks as get proffered are frequently inadequate. Also, implementation of a nominally adequate international agreement can prove to be dangerously slow (witness the disposition of surplus weapons-grade plutonium). Notwithstanding this difficulty, establishment of an unprecedented degree of international cooperation plus safeguards is a pre-requisite to a US processing scenario and its inevitable global implications. The necessary degree of international cooperation plus safeguards would, of course, be very dependent on whether reality lies in the above opinion that a bomb might be makeable from any plutonium isotopic mix or in the above opinion that practicalities due to the 238, 240 and 241 isotopes make it essentially impossible with plutonium from spent fuel taken to LWR discharge burnups. In this latter case, safeguards focus would be needed on such low burnup spent fuel that may still get produced, whether legitimately or clandestinely. Such safeguards focus is already merited.

This discussion introduces the recognition that if/when, in the long-term, processing does become economic (say because of a major and sustained uranium cost increase), processing will likely become global anyway, whether or not we are satisfied at that time with the proliferation risk. This underscores the need for timely, albeit difficult, negotiation of the necessary degree of international cooperation and safeguards in the nuclear power arena.

The plutonium weapons proliferation concerns outlined in the last two paragraphs above exist also for U-235 weapons in the non-processing (once through) scenario. Prevention of mis-use of enrichment facilities too will need greater international cooperation and improved safeguards to support a major global expansion of nuclear power. This requisite has recently been expressed by John Deutch et al. (Deutch, 2005), and has resulted in a proposal by the U.S. for an international nuclear fuel supply and take-back regime that would obviate the need for a large number of national enrichment as well as reprocessing facilities. The weak point for a much expanded global non-processing scenario is potentially more enrichment locations susceptible to rogue operation under the cover of peaceful nuclear energy programs to produce ideal weapons material. By comparison to clandestine enrichment, the processing scenario offers far from ideal weapons material but has the additional susceptibility to theft, and at multiple locations - the processing plants and the downstream fuel fabrication and nuclear power plants and transport paths between them.

The processing scenario has another weak spot. As noted above, if the motivation for processing does eventually include capping a rising uranium cost and greatly expanding the supply of nuclear fuel, the scenario must include fast reactors. But demonstration fast reactors to-date have included blankets, which produce plutonium with little 238, 240 and 241 content. This can be avoided if and while the only motivation for processing is the major increase in repository capacity achievable. For this purpose, fast reactors without blankets will suffice. Needing to be determined is whether fast reactors can also be configured to cap a rising uranium cost (i.e., breed plutonium) without producing plutonium low in 238, 240 and 241 content.

Subject to the outcome of the last challenge above, this initial evaluation does not conclude that the processing scenario is worse from proliferation considerations. It may turn out that the proliferation risk difference is not decisive and that the choice between scenarios will hinge on more tangible differences (of which there appear to be two - economics and fast reactor reliability - both encouraging us to stay with non-processing for the near-term at least).

The Hagengruber testimony (Hagengruber, 2005) also contains a relevant recommendation, which EPRI endorses:
"... take the necessary time to carry out more thorough reprocessing research to identify the most proliferation resistant and cost effective technology."
"If a reprocessing technology is determined to be adequately proliferation resistant and cost effective, reprocessing can emerge as a consensus decision with industrial, scientific, political, and public support."

A key topical aspect of this recommendation is the sequence; the consensus needs to come early. Otherwise there is a serious risk that the bulk of the available resources and of the available time will be wasted.

CONCLUSION

Integrating today's recapping and updating of findings from ten to fifteen years ago indicates that adoption of a scenario involving processing and fast reactors to achieve an extensive deferral of the need date for a second repository would carry a substantial cost burden and would carry a reliability doubt via the fast reactor element. However, trends and developments could remove these obstacles to the processing scenario, possibly before major decisions on a second repository become necessary, which need not be until around mid-century at the earliest. Besides completing the Yucca Mountain program, the two biggest and inter-related fuel-cycle needs today are for a nationwide consensus on which processing technology offers the optimum mix of economic competitiveness and proliferation resistance and for a sustained effort to negotiate greater international cooperation and safeguards. Equally likely to control the readiness schedule is development/demonstration of an acceptable, reliable and affordable fast reactor.

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