COMPARISON OF OPTIONS FOR PLUTONIUM DISPOSAL REACTORS (U)

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Executive Summary

The end of the Cold War has resulted in an excess of plutonium in the weapons stockpiles of the United States and other nations. A number of mostly reactor-based systems have been proposed to denature this plutonium, as opposed to storing and guarding it indefinitely. A Department of Energy task force has been set up to consider this problem, and the National Academy of Sciences is evaluating it as well. In this report, three major reactor types – the Advanced Light Water Reactor (ALWR), the Advanced

Liquid Metal Reactor (ALMR), and the Modular High-Temperature Gas Reactor (MHTGR), are considered in terms of various qualities applicable to plutonium denaturing. These qualities include safety, management experience, waste disposal, economics, public acceptance, and others. On the basis of these considerations, it appears that the ALWR ranks at or near the top in most categories. This reactor type deserves closer consideration in terms of plutonium denaturing and disposition.

1. Introduction

The apparent end of the Cold War has generated considerable world-wide concern about the disposal of excess nuclear weapons and weapons materials. The matter has been partially addressed by arms control agreements between the United States and the former Soviet Union, now the Commonwealth of Independent States (C.I.S.). Under already ratified agreements, about 50 metric tons of weapons-grade plutonium and 150 metric tons of highly

enriched uranium (HEU) are to be declared excess in the U.S.¹ The June, 1992 Bush-Yeltsin agreements (not yet ratified at the time of writing) state that the U.S. stockpile of warheads will be reduced by about 15,000 within a decade. September, 1992 reports^{2,3} reported that Russia was selling the U.S. tons of HEU for use, after dilution, in commercial reactors.

2. Three Options

There are at least three major approaches to disposing of excess plutonium. They can be characterized briefly as storage, vitrification and fission. In the following, each of these is described briefly, including their advantages and disadvantages. This report deals with the option of plutonium disposal by fission in reactors.

2.1 Storage

The first option is storage, either temporary or permanent. The excess stocks would be placed in guarded sites until such time as a final solution was found.

This approach can be called administrative in nature, in contrast to the two physical approaches which will be described below. The storage option, like the others, has both advantages and disadvantages. A prime advantage is that the up-front or capital costs will almost certainly be lower than that of competing options. Excess plutonium could be stored, for example, in already-existing Department of Energy sites, where strong security measures are presently in place.

A second advantage of storage is that it postpones the day of an eventual final decision. It will be noted below that not all information on the second and third options, vitrification and fission, respectively, is known. As a result, the argument can be made that storage, at least temporary will enable a more fully-informed decision to be made at a later date.

A number of disadvantages accompany the storage option. If permanent storage is envisioned, the low annual costs will mount to a large long-term cost. Because of the lengthy half-life of plutonium, measured in millennia, not years, the total eventual cost could be substantial if this route is followed.

As well, a major goal of the entire plutonium disposal process is to prevent use of the material in unauthorized ways. While government structures have, in some rare cases, worked successfully for centuries, we do not have examples of these structures, as exemplified by storage facilities, being operated for millennia. Whether or not this can be performed successfully lies in the realm of speculation.

2.2 Vitrification

A second major approach could be called vitrification or immobilization. This shares with the fission option the feature of being physical, as opposed to administrative, as in the case of storage. Briefly, the excess plutonium would be encased in some type of glass or similar material. The plutonium could be dispersed throughout the glass or be stored in its center.

The vitrification approach has major advantages over its two major competitors. First, it will be considerably more secure than storage behind barbed wire. Second, it holds out the possibility of permanent immobilization of the plutonium. Third, a number of vitrification facilities have been or are in operation throughout the world, so much is known about the technical aspects. In the United States, the Defense Waste Processing Facility (DWPF) at Savannah River Site is slated to go into operation in the near future. While not designed specifically for plutonium vitrification, in principle it could be adapted for this purpose. If security considerations were modified to allow vitrification of U.S. plutonium outside this country, the work could proceed in European facilities.

There are a number of drawbacks to the vitrification option. First, it would be considerably more expensive than simple storage. Exact figures on the costs of vitrification are not completely known, but the DWPF will, for example, costs of the order of billions of dollars. On the other hand, vitrification may be cheaper than some reactor options.

A second potential objection to vitrification is reversibility. The major goal of vitrification is immobilizing the plutonium, preventing its use. But nations with enough resources could extract the active material from the glass rods or containers. The task would be more difficult if the plutonium were dispersed in the glass, yet it still could be performed. It is true that sub-national groups would find it extremely difficult to extract the plutonium from a vitrified form, but many technically-qualified nations would be able to do so.

A third problem is the elimination of a potential energy source. The energy value of the plutonium under consideration is of the order of tens of billions of dollars, if it were

consumed in a power producing nuclear reactor. That value would disappear if the plutonium were vitrified.

This third objection relates to the debate over reprocessing, which was prominent in the 1970s and 80s. It is not the purpose of this paper to raise this issue again, but merely to note its relationship to vitrification.

However, as noted above, if vitrification were indeed reversible, the energy resource would not be lost irrevocably. The analogy to be drawn here is the proposed burial of commercial spent nuclear fuel rods under Yucca Mountain, Nevada. Under present legislation, the site would not be sealed permanently for 50 years after the last fuel rod was emplaced. This presumably would allow time for a reconsideration of national policy toward reprocessing of the plutonium in those rods.

2.3 Fission

The third and final approach to plutonium disposition is denaturing by fission. Although fissioning can be accomplished by advanced accelerators or reactors, the reactor option will form the basis for most of the rest of this paper.

There are two major advantages to this option. First, and probably most important, much if not all of the plutonium would be physically altered – denatured – into elements unusable in weapons. This physical transformation is not part of the other two options described above.

A second benefit is the production of a valuable product, electricity. The other two options produce nothing of value. This aspect has the potential for generating some public support, which will be necessary regardless of which option – or combination of options – is chosen.

There are drawbacks to the reactor option. First, while national polls have suggested broad support for using more nuclear power, for years utilities have found it impossible to

build a reactor in a specific site. The last reactor that was completed was ordered in 1974. It is likely that any new reactor, even one which eliminates plutonium permanently, will engender some public opposition. How great that will be will depend on factors beyond the scope of this paper.

A second drawback is the high initial or capital costs of the nuclear option. These up-front costs will be much greater than that of the other two options.

However, because this option will generate revenue from electricity sales the total – as opposed to capital – costs may not be as great as the other two options. This is still a matter of some debate, and can only be resolved with further economic studies.

The third drawback is that, under the three reactor options discussed in this paper, not all the plutonium will be transformed into elements which cannot be used in weapons. There will always be some plutonium left over, and it will have to be handled in other ways.

2.4 A Fourth Option?

From time to time, other options, in addition to the three major ones noted above, have been proposed. For example, some have suggested rocketing the plutonium to outer space. If successful, this clearly would have the advantage of absolutely permanent disposition.

However, these and other proposals remain only in the conceptual stage at best. They could be employed only many years in the future. One of the major requirements of present plutonium disposal options is that a solution or solutions be undertaken within the next few years. This would take advantage of the Cold War window, and accrue to the advantage of all weapons states. Waiting decades for a perfect solution to be found would preclude using this window, which may close in later years.

3. Uncertainties

All of the three major options described have major uncertainties attached. These uncertainties are political, economic, technical and of other natures.

It would take far too much space to discuss all of the uncertainties related to each of the three major options. In consequence, we have confined ourselves to mentioning these uncertainties primarily in terms of the reactor option.

Some uncertainties may be obvious; others are less so. For example, the storage option appears, at first glance, to have few uncertainties attached to it. Governments have guarded valuable objects behind barbed-wire fences for long periods. However, the uncertainty in this option arises not from present-day security systems which are acknowledged to be effective, but from the fact that security procedures would

have to last for centuries and millennia. Few if any guarantees over this length of time can be given.

The uncertainties of the reactor option are more obvious. Costs are still not completely known, although some indications, to be described below, suggest that the band of uncertainty is narrowing. Perhaps more importantly, concerns over public acceptance, as noted by Secretary of Energy Hazel O'Leary in her confirmation hearings in January 1993, remain strong. How these will affect policy toward this option is still not known.

In summary, uncertainties surround all the three major options. Further research may reduce these uncertainties somewhat, but our present state of knowledge suggests they can never be completely dispelled.

4. Previous DOE Work

These and other aspects of the plutonium disposition problem were discussed by William Young, DOE Assistant Secretary for Nuclear Energy, in setting up a Plutonium Disposition Task Force Working Group in August 1992⁴. Prior to this, some of these issues had been discussed by a DOE task force on DOE Spent Fuel Reprocessing⁵ and, around the same time, by another task force on Russian excess weapons materials.⁶

The Working Group included members of DOE headquarters staff, as well as representatives from national laboratories and other DOE facilities. The purpose of the group was to identify disposition alternatives and summarize the state of knowledge of each. Members of SRS participated in the

deliberations and preparation of materials under the leadership of Mel Buckner.

After some consideration, SRS representatives concluded that, in terms of a reactor approach to plutonium disposition, the so-called Advanced Light Water Reactor (ALWR) appears to offer the best combination of advantages for both DOE, taxpayers and the nation. A number of other plutonium disposal reactor (PDR) proposals were made to the Working Group. Of them, the liquid metal-cooled and the high-temperature gas-cooled reactors were the only major competitors to the ALWR, as discussed in a memorandum from James D. Watkins, former Secretary of Energy.⁷

5. Discussion

Two documents dealing with the ALMR and the MHTGR were submitted to the Plutonium Disposition Task Force Working Group. They are, respectively, *Excess Plutonium Disposition: Advanced Liquid Metal Reactor (ALMR)/Integral Fast Reactor (IFR)*⁸ and *Draft Report Input, NP-MHTGR, Rev. 0*.⁹

A number of other documents dealing with various potential candidate technologies for plutonium denaturing and disposition were submitted to the Working Group. They evaluated systems like molten salt reactors, particle bed reactors, accelerator-based conversion, etc. However, as noted in Section 1.4, these other systems are probably too far from construction to be useful in the short-term, regardless of their other merits. We are assuming here that a solution to the excess plutonium problem will be required in the relatively near future.

In the rest of section 2, discussions are held on the characteristics and attributes summarized in Table 1.

5.1 Safety

The Nuclear Regulatory Commission (NRC), the Advisory Committee on Reactor Safeguards (ACRS), vendors, suppliers, national laboratories, and engineering societies have developed and validated safety criteria, codes, and standards for the LWRs that are used throughout the world. Utilities share their LWR operating experiences through various owners groups and the Institute of Nuclear Power Operations (INPO).

The key question then is the relationship between ALWRs and LWRs in terms of safety. The exact relationship is at present unclear, because no ALWRs have as yet been built. However, it seems logical that at least some of the safety knowledge gained over decades of LWR experience will be applicable in terms of ALWRs. How this knowledge can be used for the other two reactor concepts is much less clear.

5.2 Vendor Competition

As indicated in Table 1, there are three U.S. vendors of ALWRs that might be considered for Pu burning, some

offering more than one potential design. This makes possible a variety of reactor sizes and types (e.g., BWR and PWR). The competition among vendors and the amortization of prior development costs should also be economically advantageous.

The other two reactor types have the potential for vendor competition. However, to date this apparently has not taken place. The situation for these latter two types might change if vendors from other countries were to enter the market.

5.3 Fuel Experience

There is extensive experience with uranium-based oxide fuels in the LWR industry, and this has made possible substantial advances in fuel technology over the past 30 years. Considerable development has been accomplished in the past. European development has continued and MOX fuel has been used on a large scale in European LWRs. The use of MOX fuel has also been successfully demonstrated in the Fast Flux Test Facility (FFTF), a U.S. sodium-cooled test reactor. It is likely that this cumulative experience is applicable to the ALWR.

An alternative for Pu burning would be a metal fuel, which has been used in the Experimental Breeder Reactor (EBR). A fuel recycle process has been investigated in this reactor, but it has not yet been demonstrated with equilibrium fission products.

Plutonium fuel of the type proposed for the MHTGR has also undergone testing. Its applicability to large-scale plutonium denaturing and disposition remains unclear. According to the MHTGR paper,⁹ design, demonstration, and performance tests are necessary to validate this fuel type.

5.4 Plutonium Consumption

Plutonium consumption rates are given according to the information provided in the three papers considered here.^{8,9}

¹⁰ The data have been shown in terms of annual plutonium-239 consumption. Note that this includes burnup of

plutonium generated by breeding in the uranium-238. This amount is largest for the MHTGR.

Operation on a short time cycle to "denature" the plutonium by building in fission products and higher plutonium isotopes is possible in each case. There is no consensus as to what would be an adequate level of denaturing. Since information on isotopic composition as a function of burnup is not available for the different reactor types, we have not attempted a comparison. Data from previous studies indicate that the accumulation of heavy plutonium isotopes would be more rapid in the ALWR and MHTGR than in the ALMR.¹¹ In the latter, Pu-241 and Pu-242 are rapidly burned and accumulate only in very small amounts. This means that the denaturing process primarily involves fission products.

5.5 Design Features

ALWR design features are based on enhancements to existing LWR design features. Some ALWR major components are being used as replacement parts in existing plants, and they are also being used in new reactors under construction in Japan and Korea. Examples of the major components being used today include highly corrosion-resistant steam generators and main condensers.

The ALMR program's reactor design effort is presently in the advanced conceptual design phase. Design features are expected to be available in full-scale prototype form around the year 2005. Examples of these features include a passive decay-heat removal system and self-cooled electromagnetic pumps for the primary sodium coolant.

The MHTGR program has completed the conceptual design phase and is about 65% through the preliminary design phase. Although the basic design draws on the technology and experience base from other gas-cooled reactor programs, certain design features are not expected to be available in full-scale prototype form until around 2000. Examples of such features include single-stage helium compressors driven by electric motors. These motors would be equipped with magnetic bearings and a passive reactor cavity cooling system (RCCS) to remove decay heat.

5.6 Construction, Startup, and Operation

The ALWR concept is based on existing LWR technology. There are multiple qualified vendor and architect engineering firms which can supply and construct the new ALWR plants. A large experienced work force already exists, including management personnel, qualified plant operators and supervisors. There is also an existing experienced LWR construction industry. However, the greatly diminished level of LWR construction in the last decade has substantially reduced the value of this last-named aspect.

Both the ALMR and MHTGR concepts are based on somewhat limited U.S. experience. An industry infrastructure to support construction, start-up and operation would need to be built up.

5.7 Waste Disposal

Current plans call for disposition of spent LWR fuel to an underground repository; ALWR spent fuel could be treated the same way. It is proposed that MHTGR spent fuel might be handled similarly. Special precautions in planning waste disposal will be required because of the potential combustibility of the graphite components in the MHTGR.

The ALMR fuel cycle involves the generation of a high-level waste containing concentrated fission products, traces of actinides and cadmium. Additional treatment of the waste stream is required prior to disposal. Processes for immobilizing and containing the final high level waste are not completely clear.

5.8 Economics

The cost of a 600 MWe ALWR reactor would be about \$1.5 to \$2 billion.¹⁰ This would include the associated MOX fabrication plant. Operating costs would be approximately \$110 million annually. The value of the electricity produced would be about \$300 million per year of reactor operation. Depending on interest rates and other factors beyond the

control of DOE, the reactor and associated facilities would have a chance to break even or possibly show a profit.^{10,12}

Cost estimates of the ALMR are speculative. It is noted in the ALMR document that "Historically, liquid metal reactors have been projected to be more expensive to build than LWRs."⁸

The ALMR document¹³ states that economy of scale and simplification (modularization) would reduce the cost per kWe in going from a 200 MWe to a 1200 MWe plant by a factor of about 60%. However, the data on which this statement is based seems theoretical.

The ALMR will have costs comparable to the ALWR and substantially less than coal-fired plants.¹⁴ However, no source is listed in the reference section for these data. The ALMR may be economically competitive with the ALWR by 2010, according to Reference 19.

The MHGTR document⁹ gives detailed economic data in its Tables 4.3.5-1 and 4.3.5-2. However, the source of these data is unclear.

It is projected that MHGTR costs will be substantial. The 4-module MHGTR design projects a cost of about \$6640/kWe installed. Operating costs over 40 years will be about 1.6 times the original capital costs. Allowing for revenue from steam and electric sales, the costs to DOE will be about \$5 billion in 1992 dollars.

Costs of the MHTGR do not include an Energy Conversion Area. It is assumed in Reference 9 that this will be designed, constructed and financed by a utility or independent power producer.

5.9 Regulatory Aspects, Design Completion and Construction Dates

By late 1991, over 700,000 man-hours of engineering had been performed on the ALWR AP-600 design. All ALWR designs are expected to be design certified by the NRC by 1995.

In terms of the ALMR, the Preliminary Safety Information Document, issued in 1986, was apparently the only document which has been submitted to the NRC. The NRC in turn published a Draft Preapplication Safety Evaluation

Report. The document stated that the "results were generally favorable." The main NRC recommendation was for "design and development [to] continue." The NRC staff will request an ACRS review letter in November, 1992, but the time and document sequence leading to final design approval is unclear. Final design certification can be expected about 2005, or about 13 years from the present.

A Draft Environmental Impact Statement (EIS) on NP-MHTGR was issued in April 1991. The design is expected to have NRC approval by 2001. This approval may be contingent on the specific concept chosen for Pu disposition.

The section in Reference 9 dealing with MHTGR regulatory issues is not completely clear. It is stated that all potential issues will be overcome, without discussion on detail.

In summary, the design approval dates for the ALMR and MHTGR are of doubtful validity. Changing regulatory and political climates make assertions of this type uncertain.

5.10 Political and Public Acceptance

Surveys conducted by the U.S. Committee on Energy Awareness and others have indicated majority support for nuclear power, using LWRs. The ALWR, as judged by its title, could be viewed as an extension of that existing industry. However, the greatly diminished level of LWR construction in the last decade has substantially reduced the value of this last-named aspect.

Little is said in Reference 8 about the relative merits of the ALMR in comparison to other types in terms of public acceptance. It is stated that discussions have been held with the NRC. However, this is not the same as public endorsement. The ALMR would have a larger plutonium inventory than other types, and this could pose a problem for public reception.

This reactor, as stated in Reference 8, is a "simplified breeder/burner." It seems likely that, on the basis of history, the word "breeder" associated with any reactor would decrease public consent.

It is assumed here that the chosen reactor would be built on a government reservation. Thus public utility commissions (PUCs) would have no direct role in choosing or approving the reactor chosen. However, if some or all of the electricity

generated were to be sold offsite, to reduce net costs to DOE, PUCs could have great indirect influence. They could impose conditions, such as setting electricity rates, to make costs to DOE higher than anticipated. The knowledge that PUCs have of the only major attempt at a U.S. LMR, the Clinch River Breeder Reactor, could influence their decisions.

Reference 9 apparently contains no section dealing with public acceptability for the MHTGR. This suggests that either the authors inadvertently left it out or that they considered it not to be an issue. However, based on the Fort St. Vrain HTGR experience, PUCs would likely be concerned. The lack of a proven reliability history for the MHTGR may influence these bodies in their deliberations.

6. Conclusion

After considering almost a dozen categories, both physical and more general, that are applicable to the subject of plutonium denaturing and disposition, we conclude that the Advanced Light Water Reactor is superior in a number of areas to the other two types evaluated. We base this conclusion on the data shown in our summary Table 1,

"Comparison of Reactor Characteristics and Attributes for Three Plutonium Disposition Concepts", beginning on p. 4-1. It stands at or near the top in almost all categories. More is known about the ALWR than the other two, especially in terms of its economics. We conclude that the ALWR should be considered carefully for this vital task.

7. References

- (1) M. R. Buckner and P. B. Parks. *Strategies for Denaturing the Weapons-Grade Plutonium Stockpile*. US DOE Report WSRC-RP-92-1004, Savannah River Site, Aiken, SC 29808, p ES-1 (1992).
- (2) "What's New Worldwide?" *Wall Street Journal Eastern Ed.* (September 1, 1992), p 1.
- (3) Russia to Sell U.S. Uranium from Scrapped Atomic Arms. *New York Times* (September 1, 1992), p A5.
- (4) Memorandum, "Initial Meeting of the Plutonium Disposition Task Force Working Group", from William H. Young, Assistant Secretary for Nuclear Energy, DOE, Washington, DC (August 10, 1992).
- (5) Task Force Study on DOE Spent Fuel Reprocessing. (February, 1992 [predecisional]).
- (6) Department of Energy, Office of Nuclear Energy, *Report on Purchase and Use of Russian Excess Weapons Materials*, (August 14, 1992 [predecisional]).
- (7) DOE Headquarters Memorandum, "Deferral of New Production Reactors Program," from James D. Watkins, Secretary of Energy, Washington, DC. (October 19, 1992).
- (8) M. Thompson and W. Hannum. *Excess Plutonium Disposition: Advanced Liquid Metal Reactor (ALMR)/Integral Fast Reactor (IFR) (Draft)*.
- (9) *Draft Report Input, NP-MHGTR, Rev. 0* (September 10, 1992).
- (10) M. R. Buckner et al. *Excess Plutonium Disposition Using ALWR Technology (U)*. US DOE Report WSRC-RP-92-1278, Savannah River Site, Aiken, SC 29808 (1992).
- (11) William Graves, Applied Physics Group, personal communication (October, 1992).
- (12) Buckner and Parks, pp 4-10.
- (13) Thompson and Hannum, pp 20-21.
- (14) Thompson and Hannum, p 22.

8. Table 1: Comparison of Reactor Characteristics and Attributes for Three Plutonium Disposition Concepts

Characteristics and Attributes	ALWR	ALMR	MHTGR
Reactor Type	Advanced light water reactor: either BWR or PWR type design	Advanced liquid metal reactor (liquid-metal fast breeder)	Modular high temperature gas cooled reactor
MWe (net)	600 up to 1300, depending on reactor design	1440 (9 reactor modules with 3 turbine generators)	533 (4 reactor modules with 2 turbine-generators)
Coolant Type	Light Water	Liquid Sodium	Helium
Moderator Type	Light Water	None	Graphite
Fuel Material	UO ₂ and/or MOX in ceramic fuel pellet	Metallic alloy of U, 25% Pu, and 10% Zr	High-enriched Pu particles
Safety	Should meet all NRC criteria and regulations – process is underway	Unclear how NRC criteria and regulations will be met	Unclear how NRC criteria and regulations will be met
Vendor Competition	Yes (3)	No	No
Fuel Experience	<ul style="list-style-type: none"> • U.S. has manufactured over 65,000 LWR fuel assemblies to date for 110 reactors • MOX fuel very similar to UO₂ • More than 20 years of MOX commercial experience in Europe and Japan • Large amounts of MOX fuel already used in FFTF • No technical issues for MOX 	<ul style="list-style-type: none"> • Uranium fuel manufactured on small scale only • Pu separations have been done on laboratory scale • Plan is to demonstrate the pyro-process fuel cycle for U and Pu combined, using the EBR-II test reactor to obtain data • MOX can be used as backup to metal fuel; large amounts of MOX fuel already used in FFTF 	<ul style="list-style-type: none"> • Coated Pu particle will need to be designed and fabrication capability demonstrated before scaling up to commercial production levels • Pu fuel performance and fission product behavior testing will need to be performed to validate design
Pu-239 Consumption Rate	<ul style="list-style-type: none"> • 0.45 kg/yr per MWe of installed generating capacity • Based on ~50% burnup of Pu in equilibrium cycle, using full MOX core and once-through fuel cycle; significant amount of Pu created by breeding in U-238 • Burnup could be increased with different core loading scheme than assumed above 	<ul style="list-style-type: none"> • 0.24 kg/yr per MWe of installed generating capacity • Based on equilibrium cycle and recycling spent metal fuel through pyro-chemical process • Large amount of Pu created by breeding in U-238 due to conversion ratio being 60% or greater (for each kg of Pu consumed, ≥ 0.6 kg is produced) 	<ul style="list-style-type: none"> • 0.77 kg/yr per MWe of installed generating capacity • Based on ~85% burnup of Pu in once-through cycle with avg. fuel assembly burnup of 700,000 megawatt-days per metric ton
Design Features	<ul style="list-style-type: none"> • Prototypes not required - based on enhancements and improvements to existing design • Being used in new power plant construction and replacement of existing components 	<ul style="list-style-type: none"> • In advanced conceptual design phase now - expect full scale prototypes by 2005 	<ul style="list-style-type: none"> • About 65% through preliminary design phase - expect full scale prototypes by 2000

8. Table 1: Comparison of Reactor Characteristics and Attributes for Three Plutonium Disposition Concepts (Continued)

Characteristics and Attributes	ALWR	ALMR	MHTGR
Construction, Startup, and Operation	<ul style="list-style-type: none"> • Multiple qualified vendors and architect engineers have built 110 LWRs in U.S. • Large pool of management personnel with construction, startup, & operations experience on LWRs • Over 3700 qualified LWR plant operators and supervisors and equivalent number in Naval Reactors Program • Extensive nuclear service industry exists to support plant maintenance and outage work 	<ul style="list-style-type: none"> • One vendor and potentially several architect engineers who may have limited experience • No management personnel with direct experience • Would have to qualify LWR operators and supervisors on ALMR simulator • No existing service industry to fully support ALMR during first few years of operation 	<ul style="list-style-type: none"> • One vendor and potentially several architect engineers who have limited experience • Some management personnel with Fort St. Vrain experience • Some operators & supervisors with Fort St. Vrain experience; would need to qualify others on MHTGR simulator • Probably no service industry to fully support MHTGR during first few years of operation
Waste Disposal	<ul style="list-style-type: none"> • Spent MOX fuel will be treated like commercial fuel and no special problems envisioned 	<ul style="list-style-type: none"> • Pyro-chemical process used to recycle spent fuel; scale-up of process may be difficult due to criticality concerns • Process waste has high level fission products in water soluble salt with small amount of actinides & heavy metals • Disposal form is uncertain; similar wastes have been difficult to process 	<ul style="list-style-type: none"> • Spent fuel in graphite blocks is proposed to be treated like commercial fuel and sent to a repository • Graphite components are combustible; special precautions would be needed for repository storage
Economics (1992 dollars)	<ul style="list-style-type: none"> • Capital costs of one 600-MWe ALWR and associated MOX fuel fabrication plant in range of \$1.5 B to \$2 B. • Operating costs for ALWR and MOX plant are \$110 M/yr • Value of electricity produced is \$300 M/yr • Potential for break-even situation for DOE 	<ul style="list-style-type: none"> • Data presented is insufficient to estimate capital and operating costs, or value of any electricity produced, for plants on-line before 2010 	<ul style="list-style-type: none"> • Capital costs of one 4-module MHTGR and Pu fuel fabrication plant in range of \$3.5 B; does not include power conversion system (turbine, generator, etc.) • Operating costs for above are \$145 M/yr • Value of electricity produced is \$108 M/yr (same \$/MWhr as ALWR) • Potential for break-even is unlikely • Above costs recalculated from original MHTGR report
Regulatory Aspects, Design Completion and Construction Dates	<ul style="list-style-type: none"> • All ALWR designs expected to be NRC certified by 1995 	<ul style="list-style-type: none"> • Design expected to be NRC approved by 2005 	<ul style="list-style-type: none"> • Design expected to be NRC approved by 2001

8. Table 1: Comparison of Reactor Characteristics and Attributes for Three Plutonium Disposition Concepts (Continued)

Characteristics and Attributes	ALWR	ALMR	MHTGR
Regulatory Aspects, Design Completion and Construction Dates (continued)	<ul style="list-style-type: none"> • ALWR certification process not tied to concept for Pu disposition • Plant construction could start shortly after certification 	<ul style="list-style-type: none"> • Design approval may be contingent on selection of concept for Pu disposition • Prototype plant would likely have to be built before commercial application possible in 2010 	<ul style="list-style-type: none"> • Design approval may be contingent on selection of concept for Pu disposition • Plant construction could start shortly after approval if testing of prototype design features is successful
Political and Public Acceptance	<ul style="list-style-type: none"> • Acceptance of ALWR likely to be higher than LWR because of major safety improvements • Surveys indicate majority public support for LWR-based nuclear power • ALWR designs incorporate lessons learned from Three Mile Island-2 	<ul style="list-style-type: none"> • LMR traditionally referred to as breeder, not consumer, of Pu • LMR operating experience not extensive like LWRs, so record of safety may not be apparent to public and public utility commissions • ALMR may have trouble gaining acceptance because of Clinch River and French SuperPhenix experience 	<ul style="list-style-type: none"> • HTGR operating experience not extensive like LWRs, so record of safety may not be apparent to public and public utility commissions • MHTGR may have trouble gaining acceptance because of Fort St. Vrain experience • Original design does not provide full containment

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