CONF-9606116-6

# Assessment of the Technical Viability of Reactor Options for Plutonium Disposition

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Paper submitted for publication and oral presentation at the *American Nuclear Society Embedded Topical Meeting "DOE Spent Nuclear Fuel and Fissile Material Management,"* Reno, Nevada, June 16-20, 1996.

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*Managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract DE-AC05-96OR22464.

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# ASSESSMENT OF THE TECHNICAL VIABILITY OF REACTOR OPTIONS FOR PLUTONIUM DISPOSITION

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## ABSTRACT

Various reactor concepts for the disposition of surplus plutonium have been proposed by reactor vendors. Not all of the concepts have attained the same level of technical viability. Studies were performed to differentiate between reactor concepts by devising a quantitative index for technical viability. For a quantitative assessment, three issues required resolution: the definition of a technical maturity scale, the treatment of "subjective" factors which cannot be easily represented in a quantitative format, and the protocol for producing a single technical viability figure-of-merit for each alternative. Alternatives involving the use of foreign facilities were found to be the most technically viable.

## I. INTRODUCTION

In September 1993, President Clinton established a policy to commit the United States to seek to eliminate, where possible, the accumulation of stockpiles of highly enriched uranium and plutonium. The U.S. Government initiated a comprehensive review of long-term alternatives for plutonium disposition, taking into account technical, nonproliferation, environmental, budgetary, and economic considerations. Part of that review - the assessment of the technical viability of various reactor alternatives - is the subject of this paper. Technical viability is defined as the degree of practicality or workability of a process, facility, or collection of facilities (termed an alternative in this paper) as determined by a scientific and/or engineering assessment.

A recent National Academy of Sciences study (NAS)[1] in 1994 ranked all of the concepts to be discussed in this paper as having the same level of technical uncertainty (low). The goal of this study was to differentiate between the reactor concepts by devising a quantitative index for technical viability. For a quantitative assessment, three issues require resolution: the definition of a technical maturity scale, the treatment of "subjective" factors that cannot be easily represented in a quantitative format, and the protocol for producing a single technical viability figure-of-merit (index) for each alternative.

Numerous individuals contributed data and assessments for the analyses described herein and a list of these individuals is provided in Greene.[2] The data/conclusions presented here are based primarily on the work of Greene,[2] but differ in some areas due to (1) additional studies performed after his publication and (2) the views of the author. The information presented in this paper, while funded by the U.S. Department of Energy (DOE), reflects solely the views of the author. The DOE is not currently sanctioning a methodology for assessing technical viability.

## II. DEFINITION OF REACTOR OPTIONS

The DOE identified nine potential plutonium disposition fuel cycles in Greene,[2] termed alternatives or variants, which are described in Table 1. All fuel cycles begin with the extraction of plutonium from existing configurations in a plutonium processing facility. This facility would be a new, government-owned establishment containing processes to convert weapons material to plutonium oxide. This oxide would be transported to a mixed-oxide (MOX) facility, which would contain equipment for blending plutonium and uranium oxides and fabrication processes for pellets, rods, and fuel assemblies. Transportation, consumption

**Table 1. Reactor Alternatives and Variants**

| ID Number[a] | Category | Description |
|---|---|---|
| R2.0 | Existing LWR<br>Base Case | • All Pu feed forms except lean scrap and irradiated fuel<br>• Separate Pu processing & fuel fab facilities<br>• Federally owned Pu processing facility in western U.S.<br>• New domestic, privately owned fuel fab facility located in southeast U.S.<br>• Complete fuel assembly fabrication<br>• No Ga or Am removal<br>• Full MOX core loaded in reactor<br>• Four privately owned BWRs located in mid-west U.S.[b]<br>• Spent fuel to federally owned geological repository in western U.S. |
| R2.1 | Existing LWR<br>Variant 1 | • Same as R2.0 except:<br>• Federally owned co-functional Pu processing & fuel fab facilities located in western U.S. |
| R2.2 | Existing LWR<br>Variant 2 | • Same as R2.0 except:<br>• Privately owned European fuel fab facility<br>• $PuO_2$/MOX fuel lag storage facility |
| R2A.0 | Partially Complete LWR<br>Base Case | • Same as R2.0 except:<br>• Two federally owned PWRs located in southeast |
| R3.0 | Evolutionary LWR<br>Base Case | • Same as R2.0 except:<br>• Two privately owned ABB-CE System 80+ reactors located in southeast U.S. |
| R3.1 | Evolutionary LWR, Variant 1, also known as Advanced LWR | • Same as R3.0 except:<br>• Four, Westinghouse PDR-600 reactors |
| R3.2 | Evolutionary LWR<br>Variant 2 | • Same as R3.0 except:<br>• Federally owned co-functional Pu processing & fuel fab facilities located in western U.S.<br>• Federally owned reactors located in southeast U.S. |
| R6.0 | CANDU<br>Base Case | • Same as R2.0 except:<br>• Two Bruce A CANDU reactors<br>• Spent fuel to Canadian geological repository |
| R6.1 | CANDU<br>Variant 1 | • Same as R6.0 except:<br>• Hybrid, reference MOX/CANFLEX, fuel-loading protocol (2 reactors with reference MOX for 5 years, then 4 reactors with CANFLEX, advanced, fuel bundle design for 10 years) |

[a] ID Numbers are from Greene, 1996.

[b] Four privately owned BWRs are a surrogate for all existing LWRs (both BWR and PWRs). In general, the throughput of four BWRs is equivalent with two PWRs. The selection of four BWRs does not necessarily represent an endorsement of this reactor option.

in reactors, and final storage in a geologic repository are the remaining parts of the fuel cycle.

## III. TECHNICAL MATURITY ASSESSMENT SCALE

An early plutonium disposition study by Omberg[3] contained a proposal for a technical readiness scale. This scale was deficient in four areas: It assumed that scientific feasibility of a concept had been demonstrated. It did not include the final phase of development, which is commercialization. It did not include the possibility that experimental work may be required in order to satisfy safety requirements. It appeared to have been based on the assumption that there were no time lags between various stages of development; no allowances were made for the loss of corporate memory due to schedule delays.

The scale of Omberg[3] was modified to include stages related to the demonstration of scientific feasibility, that is, the process under consideration has been demonstrated in the laboratory. Scientific phenomena have been confirmed, and all principles governing the behavior of the process are believed to be known.

Another modification to Omberg[3] was the addition of two final stages to designate that the process has been commercialized. These stages are the achievement of "*final application in the proper operating environment*" noted, but not included, in Omberg.[3]

A six-level regulatory status scale is shown in Table 2. Since the Nuclear Regulatory Commission (NRC) has never licensed a plutonium processing facility or a MOX fabrication facility, phases of the NRC approval are difficult to establish. The regulatory procedure for a geologic disposal facility, while formulated, has never been carried to completion. Even for reactor certification, the planned acceptance of "one-step" licensing procedures will invalidate some past experience. For these reasons, the scale shown in Table 2 is not linked to specific NRC procedures.

**Table 2. Regulatory Assessment Scale**

| Regulatory status level | Definition |
|---|---|
| 1 | No contact with regulatory agency |
| 2 | Discussions initiated with regulatory agency |
| 3 | Continuing discussions; experiment/ analyses programs defined |
| 4 | Continuing discussions; experiment/ analyses programs underway |
| 5 | Continuing discussions; experiment/ analyses programs complete |
| 6 | Final approval received from regulatory agency |

In Table 3, the regulatory status scale has been combined with the modified scale from Omberg[3] to form the reactor alternatives technical viability scale. The utility value reflects the degree of viability of a process. A value of 1 indicates low viability, or utility. A value of 12 reflects the highest degree of viability, that of a currently operating process.

The uncertainty in determining the correct level in Table 3 should decrease as the technical maturity level increases. Consequently, the maturity level scale in Table 3 probably should not be linear. However, quantifying a more appropriate function would require studies that are beyond the scope of available resources.

A subtle but important point is that the scale in Table 3 is based upon the assumption that success is possible. If a process is viable at the laboratory level but could not be developed into a prototypic process (e.g., the process is not scalable to an industrial level), the process does not remain at a utility value of 4. Instead, the function to be fulfilled by the process or facility must be degraded to a utility value of 1. The scale in Table 3 is only applicable to processes or facilities for which it is possible to progress up the scale.

An assumption of plausibility with respect to other assessment criteria is necessary for technical viability studies to be conducted independent of other assessment criteria such as safeguards or economics (i.e., in order to study *technical* viability, *not* overall viability, of a concept). In performing the technology level assessments needed for selecting a utility value from Table 3, one must assume that there are no impediments to technological development due to other criteria. Processes known to be unacceptable by any of the other criteria used by the DOE to judge overall viability must be assigned a utility value of 1 in order for the scale defined in Table 3 to be meaningful. (Uncertainty in acceptability is treated via a subjective weighting function described subsequently.) The "screening process" used to select the options described in Table 1 is intended to remove any alternatives containing processes likely to be inadequate.

## IV. OBSERVATIONS ON TECHNICAL MATURITY

Some of the functions to be performed in the plutonium processing facility have never been performed outside an engineering laboratory. Certainly, a single facility to perform all of these functions has never been built. Consequently, the technologies that are a part of the facility have been assessed to be at the lab or bench-scale level of development (i.e., scientific, but not engineering feasibility) has been demonstrated.

**Table 3. Technical Maturity Scale**

| Utility Value | Designation | Regulatory Status Scale | Comment |
|---|---|---|---|
| 1 | Conceptual | 1 | Basic principles of the concept, function, and potential application have been proposed |
| 2 | Lab-1 | 1 | Some scientific investigations (calculations and/or experiments) conducted |
| 3 | Lab-2 | 1 | Scientific investigations (calculations and/or experiments) currently under way |
| 4 | Lab-3 | 1 | Scientific feasibility demonstrated |
| 5 | Prototype-1 | 1 | A basic engineering system has been defined to implement technology principles and determine if the system can perform the function in the specific application of interest |
| 6 | Prototype-2 | 2 | Critical functions to the performance of the engineering system have been identified and verified with applicable computer codes or general experimental data |
| 7 | Prototype-3 | 3 | Design trade-offs for the engineering system have been identified to establish a reference design configuration. Initial collection of safety-related data is being performed. Existing technologies are available, but have not been applied to this application |
| 8 | Prototype-4 | 4 | The system design is complete. The technology development process begins transition into a technology demonstration. Continued data gathering to support licensing |
| 9 | Prototype-5 | 4 | The technology development process has progressed to integrated system demonstration. Collection of safety-related data is complete. Safety-related analyses continuing |
| 10 | Prototype-6 | 5 | A final design is approved or approval is pending with no outstanding issues of significance. An integrated system has been demonstrated at a scale relevant to the final application in the proper operating environment. Safety-related analyses complete |
| 11 | Commercial-1 | 6 | A facility or process is operational but lacks capacity to perform the mission or has been operational at the desired scale or throughput but is not currently in operation |
| 12 | Commercial-2 | 6 | A facility or process is operational and is available |

Reactor pins fueled with mixed oxide are not currently being fabricated in the United States. However, commercial production for MOX fuel for light-water reactors exists in Europe. Since shipping and storage technologies exist, the European fabrication option is more technically viable than any U. S. based option.[1]

The author notes that some fuel fabrication experts make no distinction between U.S. and European fabrication of MOX fuel. These experts postulate that should the DOE decide to fabricate MOX fuel in the United States, a likely scenario would be that foreign companies would be asked to construct the facility. The flaw in this argument is that it ignores the regulatory status scale presented in Tables 2 and 3. A technology that is commercially available in a foreign country is not necessarily feasible in the United States. An example would be the pharmaceutical industry in which many drugs not available in the United States are approved for use in other countries. Because regulatory acceptance is defined to be a part of the definition of technical viability, fabrication of MOX fuel in a foreign facility is at a higher level of technical viability than fabrication in the United States.

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[1] Note that all LWR options require a burnable poison to be intimately mixed with the mixed-oxide fuel or residue as a coating on the MOX fuel pellets. Neither of these processes are currently employed in European MOX pellet fabrication. If LWR cores were only partially loaded with MOX fuel (33% MOX assemblies, the remainder LEU assemblies), burnable poison would not be required. Partially loaded MOX cores were not an option selected for study.

The author also notes that for the analyses reported by Greene,[2] the DOE Technical Program Manager for the Fissile Material Disposition Program stipulated that "the President's Policy on Nonproliferation and Export Control dated September 27, 1993, states that the United States does not encourage the civil use of plutonium. It also states that we will seek to eliminate where possible the accumulation of stockpiles of highly enriched uranium or plutonium. Consistent with this, and recognizing the political reality of where we make our investments should somehow contribute to jobs in the United States, we should only consider added capacity in the United States. In this way we would be able to control its use, shut it down and decontaminate and decommission (D&D) the capability when we have eliminated our stockpile of surplus weapons material, design it specifically for our mission and create jobs in the United States. No capacity would remain to encourage civil use of plutonium. Of course the European fuel fabricators might be the parties to modify or build the capability in the United States. In addition, unused capacity over the next decade might be used to fabricate lead test assemblies and early reloads to the extent that unused capacity exists." Since essentially all European capacity is committed for the next 10 years and, under this policy, no capacity could be added to meet U.S. needs, the European fabrication option was judged in Greene[2] to be no different than that of domestic capability.

The author believes that the U.S. Nonproliferation Policy, job growth, and other political realities are not technical viability issues. They are "public acceptance" criteria and should have an impact on assessment of **overall viability** of any alternative. The author defines *technical* viability as being an assessment based on scientific and engineering feasibility under the constraint of regulatory acceptance. The impact of the U.S. Nonproliferation Policy and the current, 10-year commitment of orders in European reprocessing facilities does **not** influence the technical viability rating of the Eurofab option; it **does** however, impact the schedule for that option and results in a delay in implementing plutonium disposition under the Eurofab option.

Though only one alternative included European fabrication, it is stressed that the technical viability of any alternative would be enhanced by substituting European fabrication for domestic fabrication. However, since neither of the CANDU MOX fuels are currently being fabricated in Europe, it is questionable as to whether the technical viability of European fabrication of these fuels is the same as for currently produced, light-water-reactor (LWR) MOX fuel.

Fabrication of fuel for existing LWRs with a full core of MOX fuel (burnable poison required) would be slightly easier than fabrication for evolutionary LWRs due to the lower fissile fraction and associated, slightly reduced radiation sources. However, similarities in fuel element configuration and the common use of burnable poisons, mixed with or coated on the surface of the fuel, would likely lead to a negligible differential.

Regarding options that require domestic fabrication of MOX fuel, the CANDU reference MOX case is the most viable technically. The small size of CANDU bundles simplifies glove box production (the only option currently available in the United States) when compared with the length of LWR fuel rods (0.5 m vs. 3.7 m). The burnable poison for CANDU fuels is not an integral part of the MOX fuel as it is in all LWR and evolutionary LWR concepts. The poison is contained in a separate, depleted uranium oxide rod. Results from fuel tests for the poisoned rod are available. Test data for LWR MOX fuel with burnable poison are not available (though unpoisoned fuel data are). The fissile content of the CANDU fuel is considerably lower than in either the LWR or evolutionary LWR fuels. This lower, volumetric fissile content eases criticality safety restrictions in process equipment and reduces shielding requirements in the process facilities relative to LWR fuel. From the regulatory standpoint, the production processes for the fabrication of MOX fuel for the CANDU is the same as for the LWR—both will require review by regulatory authorities.

For the reactor concepts, the CANDU reactor operated with the reference MOX design would seem to require no modifications, making it the most technically viable reactor. Existing LWRs would require minor modifications to the control system if the entire core is to be fueled with mixed oxide. Since the evolutionary LWRs are designed for MOX fuel, there are no modifications but, obviously, these concepts have not been verified through operation. However, the CE System 80+ has progressed further in the NRC licensing process than the Westinghouse PDR 600 concept. Due to the lack of existing facilities, the level of technical viability of evolutionary reactors must be judged to be somewhat lower than that of the LWRs and CANDU.

All existing LWRs, except the partially completed ones, would require a modification to their operating licenses in order to load MOX fuel. This modification would be granted by the NRC. The CANDU reactor would also require a similar modification to its operating license from the Canadian Atomic Energy Licensing Board.

Both the partially completed LWR and the evolutionary LWRs would require the NRC to grant operating licenses. Even though the NRC would have some documentation on each of these types of reactors, obtaining an operating license indicates lower viability for the concept than modification of an existing reactor.

The advanced CANDU reactor fuel design, CANFLEX, has been fabricated and tested under expected operating conditions in a research reactor. CANFLEX bundles are scheduled for loading in an existing CANDU reactor in 1997. However, as for reference CANDU MOX fuel, a mixed oxide CANFLEX bundle has never been fabricated. Since option R6.1 does not call for introduction of CANFLEX fuel until five years after irradiation of the first MOX bundle and considering the current status of CANFLEX bundle demonstration, this option is judged to have the same level of technical viability as the reference CANDU option, R6.0. Note that the delayed introduction of an "advanced" concept is unique to the CANDU variant; the evolutionary LWR variants have no such transition phase.

The repository facility is the same for all options except the CANDU alternatives. The Canadian repository is based on the same philosophy as the U.S. facility—contained, deep underground storage. There has been and continues to be a sharing of technical information on waste repositories between the United States and Canada. However, the Canadian government has not chosen a site for the repository. Instead, the Canadian government is pursuing development of a site-independent design concept. The conceptual design will be presented to the Atomic Energy Licensing Board. Subsequently, site selection will be made. Since, unlike the United States, no preliminary site construction has been initiated, the CANDU repository option is less viable than the LWR concepts.

## V. SUBJECTIVE TECHNICAL VIABILITY FACTORS

Creation of a technical maturity scale does not allow a complete assessment of technical viability. Assessments based on Table 3 consider only the current status of a given process and are made under the assumption that the process is independent of all others. The importance of a process relative to all others that compose an alternative must also be assessed.

A process may have a high maturity value, but there may be considerable uncertainty regarding advancement along the scale. A process with a low maturity ranking may be known to be easy to commercialize. A process may have been commercialized at some time in the past, but changes in regulatory statutes might prohibit current-day operation. A process may be ancillary to the production of the final product, or it may be "on the critical path." Alternative or "fall-back" processes may or may not be available. It is not obvious how one should compare an alternative in which all but one process have very high maturity values, but that one process has a very low maturity value with another alternative in which all processes have mediocre maturity values.

To compensate for the weaknesses of the technical maturity scale, a subjective weighting function was created and applied to all reactor concepts. This function is shown in Table 4. The weighting function was defined by the participants in Greene[2] and the function incorporated assessments of several issues. The importance of a given process relative to all other processes in the alternative was a factor. The perceived risk of attaining the next stage of maturity was included. The availability and level of development of substitutes for a process should failure of the given process occur were considered. The status of regulatory review (active or dormant) was included.

The weighting function consists of a numerical value assigned to each process in a facility. The default value of the weighting function for a process is 1.0 (simple average). The minimum value of the function is 0.0, and the maximum value is open-ended. A weighting function value of 1 implies that a process is neither more nor less important than other processes that form the alternative.

## VI. DERIVATION OF A TECHNICAL VIABILITY INDEX

Each facility in the reactor alternatives is composed of processes, and each process is at some stage of development. These processes are identified in Greene[2] and are listed in Table 4. For each process in each reactor alternative, the degree of technical viability is assessed, based on the categories defined in Table 3 and the observations presented in Section IV. Each process is evaluated under the assumption that preceding processes are accomplished successfully (i.e., each process is evaluated independently from all other processes that form the alternative).

## Table 4. Technical Viability Rankings for Reactor Alternatives

| Process | Weight | R2.0 | R2.1 | R2.2 | R2A.0 | R3.0 | R3.1 | R3.2 | R6.0 | R6.1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Shipping to Pu Proc. | 1.000 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Pu Proc.-receiving | 1.000 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Pu Proc.-Pit and Metal processing | 0.650 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Pu Proc.-U/Pu Oxide processing | 0.050 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Pu Proc.-Halide Salts/Oxide processing | 0.050 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Pu Proc.-Oxide-like Materials processing | 0.050 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Pu Proc.-Alloy Reactor Fuel | 0.050 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Pu Proc.-SS&C, Impure Metal & Pu Alloys | 0.050 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Pu Proc.-Clean oxide, Impure oxide and Oxide Reactor Fuel | 0.100 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Pu Proc.-sinter & convert part. size | 1.000 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Pu Proc.-shipping | 1.000 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Fuel Fab-Pu receiving & storage | 0.200 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Fuel Fab-Non-Pu receiving & storage | 0.200 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Fuel Fab-Pu oxide purification | 1.000 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Fuel Fab-feed materials prep. | 1.000 | 4 | 4 | 6 | 4 | 4 | 4 | 4 | 7 | 7 |
| Fuel Fab-fuel pellet fab. | 1.000 | 6 | 6 | 8 | 6 | 6 | 6 | 6 | 7 | 7 |
| Fuel Fab-fuel rod fab. | 1.000 | 6 | 6 | 11 | 6 | 6 | 6 | 6 | 7 | 7 |
| Fuel Fab-fuel bundle assembly | 1.000 | 7 | 7 | 11 | 7 | 7 | 7 | 7 | 9 | 9 |
| Fuel Fab-materials recycle | 0.500 | 7 | 7 | 11 | 7 | 7 | 7 | 7 | 7 | 7 |
| Fuel Fab-waste management | 0.500 | 9 | 9 | 11 | 9 | 9 | 9 | 9 | 9 | 9 |
| Fuel Fab-bundle shipping | 0.200 | 9 | 9 | 9 | 11 | 9 | 9 | 9 | 9 | 9 |
| Reactor-fresh MOX storage | 1.000 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Reactor-fuel storage pool | 1.000 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 12 | 12 |
| Reactor-core configuration | 6.533 | 8 | 8 | 8 | 7 | 8 | 7 | 8 | 8 | 8 |
| Reactor-spent fuel storage pool | 1.000 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 12 | 12 |
| Reactor-dry spent fuel storage | 1.000 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 12 | 12 |
| Reactor-shipping | 0.200 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 8 |
| Repository-surface, security | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-surface staging area | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-surface receiving bay | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-surface, handling cells | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |

**Table 4. (continued)**

| Process | Weight | R2.0 | R2.1 | R2.2 | R2A.0 | R3.0 | R3.1 | R3.2 | R6.0 | R6.1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Repository-surface, *welding* | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-surface, decontamination | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-surface, vault | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-surface, transfer area | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-surface, cask maintenance | 0.100 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-surface, waste treatment | 0.050 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-subsurface, emplacement | 0.050 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Repository-geologic facility postclosure isolation and safety | 2.000 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 |
| Sum | 25.333 | 316 | 316 | 335 | 317 | 300 | 299 | 300 | 315 | 315 |
| Weighted sum | - | 197.98 | 197.98 | 213.98 | 192.12 | 190.98 | 184.72 | 190.98 | 205.18 | 205.18 |
| Unweighted viability factor | - | 8.10 | 8.10 | 8.59 | 8.13 | 7.69 | 7.67 | 7.69 | 8.08 | 8.08 |
| Weighted viability factor[b] | - | 7.90 | 7.90 | 8.54 | 7.66 | 7.62 | 7.37 | 7.62 | 8.19 | 8.19 |

[a] Includes blending to create "master mix" MOX and MOX lag storage facility. These items not present in other alternatives.
[b] Weighted viability Factor = Weighted sum/sum of weights. A value of 12.0 means the alternative is commercialized; a value of 1 means that the alternative exists in theory.

The overall figure-of-merit or technical viability index for each alternative/variant is derived by summing over all processes from all facilities, the product of the technical maturity values (from Table 3) assigned to the processes and the weighting or "importance" function values. This sum is then divided by the summation of the weighting function values for all processes. The resulting quotient is the desired figure of merit. Consequently, the highest possible figure of merit for an alternative is 12. The lowest possible value is 1.0.

Several of the subjective weighting values listed in Table 4 differ from unity. Justifications for all non-unity assignments are provided subsequently.

The non-unity plutonium processing weight functions were defined based on the relative quantities of material expected to be received at the processing facility, that is, 65% of the material is expected to be in the form of metal, 35%, in other forms.

The fuel fabrication receiving and storage functions were judged to be equivalent in function and difficulty-of-design as existing facilities and were assigned a weight *less than 1. The fuel fabrication materials recycle and* waste management processes were judged less important than the other fabrication processes because problems or delays in performing these functions could occur without necessarily interrupting the fabrication of MOX fuel. The assignment of 0.5 reflects that these are lesser but still important functions. Shipping of fresh fuel to the reactor and spent fuel from the reactor were judged to be relatively simple items to commercialize and were assigned a weight of 0.2.

The reactor core configuration was assigned a large weight (25% of the sum of all weights) because it is *the process* by which the weapons-grade plutonium characteristics are modified to be similar to spent fuel from commercial reactors. All reactor processes, except core design, were assigned lower weights because of a judgement that the qualification of the balance-of-plant was considerably easier to accomplish than the core design.

The sum of the weights for all surface repository processes was set equal to 0.1 due to the simplicity of these operations as compared with other processes in the alternative. The repository cask maintenance and waste treatment process values were reduced further by a factor of 2 from the other surface processes because problems or delays in performing these functions could occur without necessarily interrupting the storage of spent fuel. The subsurface portion of the repository was assigned a weight of 2 because recovery from failure of this process would be more difficult than recovery from the failure of other processes.

Though not considered in the current work, a different weighting for the subsurface portion of the repository would be required for other plutonium disposition options (immobilization or storage in a borehole) being studied by DOE. Whereas the reactor core design process achieves the goal of transforming weapons-grade plutonium for the reactor options, plutonium/fission product vitrification and subsurface storage are the principal process for achieving the disposition goal for the immobilization and borehole options, respectively.

## VII. CONCLUSIONS

Alternatives involving the use of foreign facilities are the most technically viable. The use of an existing LWR for plutonium disposition with an existing, foreign fuel fabrication facility ranks first, followed by the CANDU alternatives. However, as is noted in NAS,[1] there is little difference in technical viability among alternatives due to a large number of processes being independent of the choice of a reactor.

Two of the existing, LWR concepts have the same viability factors because the distinguishing factors between these variants are related to economics, not technology. The evolutionary reactors rank only slightly lower than existing reactors because these designs incorporate relatively small advances in technology and many of these advanced technologies have been demonstrated individually (and sometimes together as systems) in existing domestic and foreign reactors. The two CANDU options have identical rankings because the alternatives are identical for the first 5 years and advanced, CANFLEX fuel qualification is scheduled for 1997.

The use of a subjective weighting function is seen to have some impact on the interpretation of the technical maturity assessment. All processes rank lower on the viability scale when subjective weighting is included in the analyses (comparing the last two rows of Table 4).

This methodology results in an index for technical viability which can be used in decision analyses to compare overall viability of disposition concepts. The methodology is a combination of subjective and objective assessments. The maturity levels of processes that compose a disposition alternative are defined objectively. The relative importance of various processes to the success of the alternative in meeting the mission goal is assessed subjectively by technical experts.

## ACKNOWLEDGMENTS

This research was performed at the Oak Ridge National Laboratory, managed by Lockheed Martin Energy Corp. for the U.S. Department of Energy under contract DE-AC05-960R22464.

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