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PLUTONIUM ASSESSMENT MODELING--GOVERNMENT POLICY, NON-PROLIFERATION, AND THE GOVERNMENT FENCE

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Assessment modeling for the evaluation of plutonium as an energy resource is stressed, and generic mathematical model forms are outlined. Representative necessary objective functions are developed. Constraints and assumptions are listed. An example involving present-day light water reactor technology is demonstrated. Technical, environmental, and political implications are drawn. Specific new directions for analysis are suggested. The position of the boundary of government control and responsibility--the government exclusion fence--is shown to be a critical, but overlooked, constraint. Existing governmental uranium stockpiles may be an unmentioned, though important, constraint.

Plutonium is the most abundant proven energy equivalent and most controversial energy resource. Plutonium results from an intermediate nuclear reactor processing stage starting with the raw material uranium-238, U-238. Therefore, the plutonium resource differs from the U-238 resource only through minimal conversion losses and through the political and/or social will to perform the conversion. The quality of the U-238 resource, from which plutonium for the breeder is produced, in relation to other more commonly used fuel resources, is displayed in Figure 1. The relative abundance of U-238, and therefore of plutonium is high. There is, indeed, a great need to assess plutonium in relation to the potential available energy for a society in short supply.

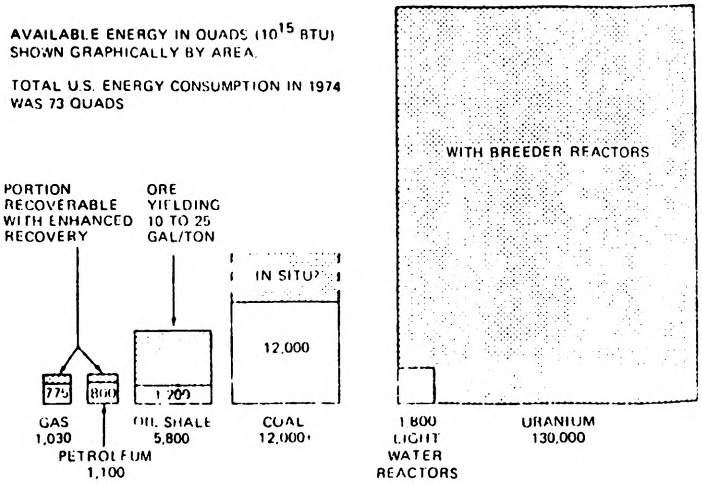

Figure 1. Available Energy from Recoverable Domestic Energy Resources

Plutonium, like coal and other energy resources, is obtained in various forms, each presenting different opportunities for application and challenges for safe clean use. Table 1 shows the characteristics of plutonium found in a representative quantity of spent fuel from present light water reactors. As with other energy producing materials, one constituent of spent nuclear fuel is a harmful waste that must be responsibly managed. This is the highly radioactive fission product material. In addition, the proliferation and/or diversion aspects of plutonium fuel as a weapons material have received much public and political attention. As shown in Table 1, commercial reactor produced plutonium contains approximately 25% even numbered isotopes, Pu-238, 240, and 242. The relative capture to fission probabilities for these isotopes is extremely high compared to those for the highly fissionable odd-numbered isotopes. The capture process defeats fission and the chain reaction. It is possible to construct a weapon using plutonium with 25% non-fissionable material but the result is unpredictable and unmanageable. The key point is that if there were no good quality weapons material or only small quantities of such material in existence, the production of any quantity of poor quality weapons grade material could affect domestic or international stability. With large quantities of good quality weapons material in existence, the addition of small amounts of poor quality material, if handled in similar fashion to the high quality material, should have little or no effect at all.

Table 1. Composition and Properties of Light Water Reaction Generated Plutonium

Isotope	Capture(1) Cross Section (Barns)	Fission(1) Cross Section (Barns)	Atomic Fraction of All Pu	% In Reactor
238	403	16.8	.015	0.0135
239	315	748	.609	0.5481
240	250	0.03	.204	0.1866
241	390	1010	.132	0.1188
242	19	0.2	.040	0.0360
			1.000	0.9000

Within the governmental sphere of influence, the uranium fuel cycle is closed, plutonium is produced, and enriched and unenriched uranium stockpiles exist; all in significant proportions. The activities of the Departments of Defense and State in regard to nuclear weapons and international nuclear materials agreements are not extensively discussed in the popular press. Many nuclear energy related activities of the agencies now part of the Department of Energy are discussed extensively. Uranium and plutonium resources are of importance to the Departments of Energy, Defense, and State. Decisions by one department affect the availability of these resources for the needs of the other departments. Outside of the government influence, a comparatively small, but critically important commercial nuclear power venture exists. Proper assessment will compare governmental and commercial efforts as appropriate. For example, a commercial power reactor or any of its components should not be compared to a bomb; however, reprocessing for plutonium bombs in the Department of Defense must be compared to reprocessing for commercial nuclear power, especially in view of Executive claims of moral leadership. To obtain plutonium from spent reactor fuel, the material must be separated from other hazardous material, chemically processed, and enriched--all requiring essentially the same extensive facilities necessary to obtain the weapons material from the natural resource. Federal facilities have been producing large quantities of weapons material for over thirty years. Specially designed reactors, unlike commercial power reactors, are used. These special reactors have high proportions of Pu-239 and Pu-241 and low proportions of Pu-238, 240, and 242 in their offloaded spent fuel. The offloaded fuel is processed to obtain the high quality weapons grade material and the high-level radioactive wastes are managed on site. At present, there are 80 million gallons of these defense-generated wastes stored at government sites in this country (2). If the commercial nuclear power program is expanded according to the most optimistic projections, the high-level wastes will accumulate to 20 million gallons by the year 2025. This country is reprocessing and producing plutonium of weapons quality in large quantity. The White House is presently showing great concern about reprocessing commercial reactor generated spent fuel. This spent fuel will provide extensive energy generation materials which, relative to defense generated materials, are much smaller amounts of poor quality weapons material.

The Ford Policy of 28 October 1976 and the Carter Policy of 20 April 1977 focus on the non-proliferation aspects of spent light water reactor fuel. Such a policy makes the nation strongly dependent on adequate uranium supplies. Errors in difficult resource estimates could yield extremely harmful results. History has shown other cases in which shortages of energy producing materials led to pressures resulting in overly-optimistic resource estimates (3). The unexpectedness of the proportions of the pesent oil and natural gas shortages are, in part, a result of over-zealous resource estimates.

Plutonium exists in spent fuel, and all alternatives for disposition involve the consideration of non-proliferation. Given a need for energy resources, an alternative can be chosen to minimize proliferation; or conversely, given the goal of non-proliferation, an alternative can be chosen to maximize energy resources. The results are not necessarily the same. Alternatives can be assessed with certain goals for the objective function and others for the constraints. By reversing the orientation of the same goals, other objectives are defined with other constraints. The evaluation of the results, which will be different for these cases, <u>must</u> take into account which goals were the objective and which the constraints. There is present emphasis on a thorium fuel cycle which will not resolve the non-proliferation issues; and the development of the neutron bomb constitutes indirect proliferation, in that it forces other nations to develop the same technology out of fear or competitive spirit. For other energy sources, technical assessment and environmental assessment are balanced for intelligent management decision-making. For plutonium, technical, environmental, and foreign policy assessments must be balanced. However, these perspectives are not usually integrated, little experience exists, Department of Defense programs dealing with large amounts of plutonium are not discussed, and the State Department perspective is dominating and dictating the framework of the other perspectives.

Assessment of plutonium begins with the assessment of spent-fuel alternatives. The various alternatives affect the entire nuclear fuel cycle. Figure 2 shows the nuclear fuel cycle, in which uranium ore is mined and milled to obtain uranium oxide. The uranium oxide is chemically converted to gaseous UF_6 in preparation for enrichment in which the concentration of the fissile isotope U-235 is increased mechanically from its natural .711% to between 2% and 4%. The enriched uranium fuel is chemically converted to UO_2 powder which is pressed into pellets that are sintered and loaded into fuel rods. The fuel rods are fabricated into fuel assemblies which are inserted into a reactor. Fuel assemblies typically reside in the reactor core for three years after which time they are stored for cooling and can then be reprocessed. The crucial stages of the fuel cycle are (1) the resource, due to the uncertainty of its extent; (2) enrichment, due to the existence of competing technologies, indecision about the desirability of government control, and questions about the adequacy of the capacity; and (3) spent-fuel disposition, due to the issues of waste management, proliferation, and diversion. The individual crucial stages cannot be evaluated in a vacuum because the fuel cycle links the stages and indeed contains a feedback loop. Therefore, no single stage can be evaluated without considering its influence on the others. For example, it is inappropriate to assess plutonium without knowing the extent of the alternative uranium resource and the extent of the enrichment capability to produce U-235.

Modeling techniques have been developed to assess impacts on and effects of the nuclear fuel cycle. Interrupted fabricated fuel supplies (5) and in-process fabrication plant inventories (6) have been analyzed. Alternative nuclear fuel sources including reprocessed spent fuel have been evaluated under both present and anticipated in-core fuel management schemes (7,8). These analyses highlight the relationship between the uranium resource and plutonium. Strategies for the management of spent fuel have been evaluated with respect to the provision of adequate storage capacity (9), the

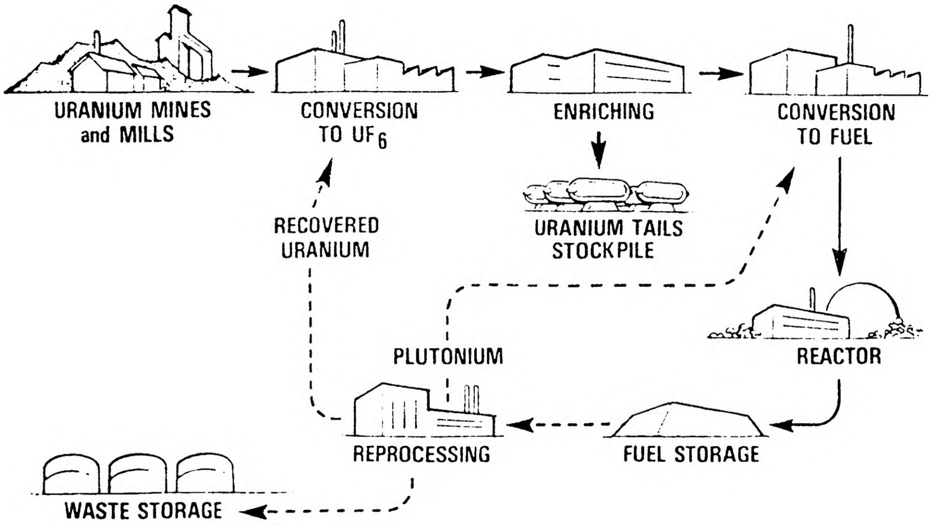

Figure 2. Nuclear Fuel Cycle

optimal inventory withdrawal sequence (10), the economic life of the spent fuel (10), and optimal approaches to spent-fuel transport (11). The effects on the fuel cycle of new enrichment technology development have been reported (12).

Well-known and often-used generic types of decision-making strategies and models are used for plutonium assessment. A few examples exist through recent and current modeling efforts. Analyses include resource allocation, inventory analysis, process auditing, and decision theory.

Integer Programs are a class of Linear Programs. They are used to model problems in which system relationships are linear but in which the decision variables must take on discrete values. The generic format of an Integer Programming model is:

$$\text{Extremize} \quad \sum_j c_j x_j \qquad (1)$$

$$\text{subject to:} \quad \sum_j a_{ij} x_j \le b_i$$

$$x_j \ge 0 \text{ and integer } \forall j.$$

This basic model form is applied to the problem of determining economically optimal patterns of withdrawing spent fuel from storage upon the resumption of reprocessing. The realization of the Integer Program when applied to the spent-fuel withdrawal problem is:

$$\text{Minimize} \quad \sum_{i=1}^{t_f} \sum_{j=1}^{t_f} c_{ij} x_{ij} \qquad (2)$$

$$\text{subject to:} \quad \sum_j x_{ij} \le a_i$$

$$\sum_i x_{ij} \ge b_j$$

$$x_{ij} \ge 0 \text{ and integer } \forall i,j$$

where x_{ij} is the number of spent fuel assemblies generated in year i that are withdrawn from storage and reprocessed in year j, a_i is the quantity of spent fuel generated in year i, and b_j is the reprocessing capacity in year j. The constraints require that no more fuel be withdrawn than exists and that as much fuel as possible be reprocessed. The constraints become equalities with the addition of slack variables that represent resulting remaining inventories. The parameter c_{ij} is the cost associated with withdrawal of spent fuel generated in year i for reprocessing in year j. By including material decay costs, inventory holding costs, recycled material values, and reprocessing tarrifs in these parameters, the costs are applied to both the decision variables and the slack variables and represent the economics of spent fuel management.

The above defined model is applied to the reference case of all light-water-reactor spent fuel expected to be generated under Scenario D of WASH 1139 (13) for the rest of the century. Results of the analysis indicate that, from the utility perspective, a last-in-first-out inventory withdrawal policy is optimal and that existing stockpiles of spent fuel are never depleted.

Mixed Integer Linear Programs are another class of linear programs. They also model problems with linear system relationships but restrict only a subset of the decision variables to be discrete. The generic form of a Mixed Integer Linear Program is:

$$\text{Extremize} \quad \sum_j c_j x_j \tag{3}$$

$$\text{subject to:} \quad \sum_j a_{ij} x_j \le b_i$$

$$x_j \ge 0$$

$$x_j \text{ integer } j \varepsilon R$$

where R is the index set of integer variables. This basic model form is applied in coordination with an Integer Program to analyze the problem of identifying strategies for replacing uranium fuel with mixed-oxide fuels in order to minimize uranium consumption. The replacement opportunities considered include the use of mixed-oxide fuels in plutonium-burning and self-generating non-breeder reactors. The Mixed Integer Linear Program is used to determine the best mixed-oxide fuel blending plan for mixing recycled plutonium with uranium. The results of this analysis provide the parameters for an Integer Program, the objective of which is to identify the allocation of fuel types that will minimize overall uranium consumption. By defining the decision variable as $x_{ijt} = 1$ if type i fuel is used in reactor j in year t, and 0 otherwise, the Integer Program takes the form:

$$\text{Minimize} \quad \sum_{t=1}^{T} \sum_{j=1}^{J(t)} \sum_{i=1}^{I} c_{ijt} x_{ijt} + s(P_t + Q_t) \tag{4}$$

subject to:

$$\sum_{i=1}^{I} x_{ijt} = 1; \tag{5}$$
each reactor must be fueled with only one type of fuel each year,

$$\sum_{i \varepsilon F} \sum_{j=1}^{J(t)} q_{ijt} x_{ijt} \le M_{t-1}; \tag{6}$$
the quantity of mixed-oxide fuel used in reactors in a given year cannot exceed the mixed-oxide fabrication capacity of the previous year,

$$\sum_{i \varepsilon H} \sum_{j=1}^{J(t)} q_{ijt} x_{ijt} \le U_{t-1}; \tag{7}$$
the quantity of uranium fuel used in reactors in a given year cannot exceed the UO_2 fabrication capacity in the previous year,

$$\sum_{i \varepsilon FUH} \sum_{j=1}^{J(t)} d_i q_{ijt} x_{ijt} \le D_{t-1}; \tag{8}$$
the enrichment capacity cannot be exceeded when processing fuel materials,

$$\sum_{i=1}^{I} \sum_{j=1}^{J(t)} b_i q_{ijt} x_{ijt} \le P_{t-1} + \sum_{i=1}^{I} \sum_{j=1}^{J(t-5)} e_i q_{ijt-5} x_{ijt-5}; \tag{9}$$
plutonium utilization must not exceed supply,

$$P_{t-1} = \sum_{k=0}^{t-2} \left[\sum_{i=1}^{I} \sum_{j=1}^{J(k)} e_i q_{ijk-5} x_{ijk-5} - b_i q_{ijk} x_{ijk} \right]; \tag{10}$$
the plutonium stockpile is quantity available less amount recycled,

$$\sum_{i=1}^{I} \sum_{j=1}^{J(t)} g_i q_{ijt} x_{ijt} \le Q_{t-1} + \sum_{i=1}^{I} \sum_{j=1}^{J(t)} h_i q_{ijt-5} x_{ijt-5}; \tag{11}$$
recycled uranium utilization in all fuels must not exceed available supply,

$$Q_{t-1} = \sum_{k=0}^{t-2} \left[\sum_{i=1}^{I} \sum_{j=1}^{J(k)} h_i q_{ijk-5} x_{ijk-5} - g_i q_{ijk} x_{ijk} \right]; \tag{12}$$
the uranium inventory is quantity available less amount used,

$$x_{i'j't'} = 0, \quad x_{i''j''t''} = 1; \tag{13}$$
designated decision variables are fixed, and

$$x_{ijt} \ge 0; \tag{14}$$
decision variable nonnegativity,

where the parameters included in the model are:

C_{ijt} = the cost of using type i fuel in reactor j in year k,

S = inventory holding cost,

q_{ijt} = the quantity of type i fuel that would be required to fuel reactor j if type i is used in year j in year t,

F = the subset of fuel types corresponding to mixed-oxide fuel,

H = the subset of fuel types corresponding to uranium fuel,

M_t = the mixed-oxide fuel fabrication capacity in year t,

U_t = the uranium fuel fabrication capacity in year t,

D_t = the enrichment plant capacity in year t,

d_i = enrichment processing requirement for one unit of product fuel of type i,

b_i = percentage of plutonium in one unit of type i fuel,

e_i = percentage of spent type i fuel that is recycleable plutonium,

h_i = percentage of spent type i fuel that is recycleable uranium,

g_i = percentage of fresh type i fuel that is recycled uranium,

Q_t = recycled uranium stockpile, and

P_t = recycled plutonium stockpile.

This model formulation provides an application of integer programming to a problem in which uranium consumption is minimized. The model represents the use in light water reactors of mixed-oxide fuels to conserve domestic uranium resources.

Linear programming is a modeling format used for **planning allocation** constrained resources among **competing activities.** It is the general class of **models of which** Integer Programs and Mixed Integer **Linear Programs** are classes. The generic Linear **Program** for is to:

$$\text{Extremize} \quad \sum_j c_j x_j \qquad (15)$$

$$\text{subject to:} \quad \sum_j a_{ij} x_j \leq b_i$$

$$x_j \geq 0 \quad \forall j$$

This general form is used to analyze the relative **appeal of** various nuclear reactor fuel resources. **The resources** considered are domestic mined **uranium,** foreign mined uranium, mill tails, enrichment tails, and uranium from reprocessed spent fuel. The linear program representing this problem is:

$$\text{Minimize} \quad \sum_{j=1}^{5} (f_j + s_j) x_j$$

subject to:

$a_j x_j - m_j$, j=1, 5; no more material can be obtained from any given source than is available in that source, (16)

$x_1 + x_3 \leq d_1$; the quantity of material obtained from mill tails and domestic ore cannot exceed the capacity of domestic mills to process it, (17)

$x_2 \leq d_2$; material from foreign mines cannot exceed the foreign milling capacity, (18)

$x_1 + x_2 + x_3 \leq d_3$; the quantity of material that is used and requires refining cannot exceed the hexafluoride conversion plant output capacity, (19)

$x_5 \leq d_4$; the fuel derived from spent-fuel reprocessing cannot exceed the reprocessing plant capacity, (20)

$\sum_{j=1}^{5} e_j x_j \leq E$; enrichment requirements must not exceed enrichment plant capacity, (21)

$\sum_{j=1}^{5} b_j x_j \geq D$; the fuel produced must satisfy the demand for fuel, and (22)

$x_j \geq 0$ j=1, 5; decision variable nonnegativity(23)

where

m_j are the source material availability limits,

a_j are the inverses of the source material to pre-enrichment material efficiency factors,

d_1 is the domestic mill output capacity,

d_2 is the foreign mill output capacity,

d_3 is the hexafluoride conversion plant output capacity,

d_4 is the reprocessing plant output limit,

e_j are the enrichment plant processing requirements per MTU of pre-enrichment fuel,

E is the available enrichment capacity,

b_j are the enrichment plant material efficiency factors,

D is the total demand for product fuel,

s_j is the cost of fuel enrichment,
f_j is the cost of feed material, and
x_j is the quantity of type j fuel produced.

For reference case data corresponding to annual fuel demands over a twenty-year horizon, results of the analysis of the model indicate a clear preference for reprocessed fuel material even without plutonium recycle. Sensitivity analysis of the model results indicate that severe increases in reprocessing costs do not force recycled uranium out of the optimal solution. Thus, uranium resources can be conserved sufficiently to justify reprocessing for recycleable uranium. Inclusion of the further resource conservation and economic advantages associated with plutonium recycle can be assessed by sensitivity analysis and serve to reinforce the appeal of spent fuel as a reactor fuel resource.

Simulation is a tool particularly well suited for assessment studies. Simulation can be used to experiment with the influence of uncertainty upon a decision problem and can also be used to imitate the behavior of a system under specific operating conditions. A particular simulation model was developed to represent the sequential production and inventories of nuclear fuel materials in the fuel cycle. The objective of the model is to determine the most efficient stockpile points in the fuel cycle in order to avoid interruptions in reactor fuel supply. The stagewise model with variational stage returns was applied to the nuclear fuel cycle over a twenty-year horizon. Results of the analysis emphasize the interrelationship of the resource, enrichment capacity, and the spent fuel resource. The results consistently demonstrate a balance of the three stages in order to assure adequate reactor fuel supplies.

Decision theory is a subdiscipline directed at evaluation of problems of choice under imperfect information and in which additional information is available at a price. One model form used frequently in decision theory is the Bayesian model in which the quality or quantity of information is augmented sequentially. By applying a cost per stage for information improvement, a model can be constructed to assess spent-fuel disposition alternatives. If at each stage, an experimental outcome B_j is obtained from the set of outcomes, then the estimated probability of a given state of nature A_i among those possible is given by:

$$P_t(A_i|B_j) = \frac{P(B_j|A_i)P_{t-1}(A_i)}{\sum_{i=1}^{N} P(B_j|A_i)P_{t-1}(A_i)} \qquad (24)$$

This information improvement equation is incorporated into a stagewise recursion equation that defines the value to a decision maker obtained from improved information. The process can be terminated after any stage by specifying a decision. Once a decision is made, its consequences follow with an associated resulting payoff. In the context of assessment of spent-fuel disposition alternatives, research and development or international diplomacy can be represented as specific stage experiments concerning spent-fuel management.

Thus, generic types of decision models can be used for plutonium assessment. In constructing the mathematical models, the perspective from which the objective and constraints are specified determines the realized form and the relationships that can be assessed.

Alternatives for the disposition of spent fuel in the most general sense are dependent upon the type of reactor under consideration. Alternatives are being evaluated for 1) the present light water reactor, 2) the liquid metal fast breeder reactor, 3) both thermal and fast gas-cooled reactors, 4) the heavy water reactor, and 5) combinations of reactors including the light water reactor-heavy water reactor uranium-plutonium tandem and energy centers containing different fuel cycle concepts. Concepts are suggested for extending fuel exposure or efficiency without chemical processing. The concepts include 1) the tandem cycle, where spent fuel from the light water reactor is further irradiated in a heavy water reactor or other suitable reactor; 2) extended burnup, where fuel is retained in the light water reactor for extended periods of time; and 3) fuel rejuvenation, where spent fuel from the light water reactor is reenriched without reprocessing. For the light water reactor using today's uranium-type fuel, concepts include 1) full reprocessing, where both the uranium and plutonium values in the spent fuel are separated and recycled; 2) partial reprocessing, where lethal fission product material is retained in the separated plutonium and the uranium and plutonium are recycled; 3) coprocessing, where the uranium and plutonium are maintained as a single product from the process; 4) throwaway cycles, where plutonium and/or uranium are placed in permanent disposal; and 5) stowaway cycles, where plutonium and/or uranium are placed in retrievable storage. In addition, there are similar concepts based on the thorium fuel cycle. There are many advantages and disadvantages related to these many alternative concepts including the state of the existing technology, economics, diversion, projected fuel resource, proliferation, and environmental impact. Any of these relative advantages can be viewed from global or limited perspectives and can be constrained by the views of the utility, the reactor vendor, the consumer, and any one of various government agencies.

Under present administrative policy, spent fuel is being stored in ever increasing amounts in open spent-fuel basins. Meanwhile, the emphasis is on reviewing previously discarded alternatives while discarding developed alternatives. Simultaneously, U.S. energy problems grow. Thus, the present policy is not a decision; but, given typical technology development lead times, may in fact become an irreversible and unplanned decision.

Assessment models for the entire spent-fuel disposition problem are either too superficial and limited or too extensive to solve with present techniques and computer facilities. This is especially true when attempting to include social and/or political impact. This is not, however, sufficient reason to abandon the assessment process. Either limited models or models devoted to a specific aspect of the problem must be developed. The results must be evaluated with a complete understanding of the perspective, goals, objective, constraints, and limitations of the model. After a sufficient number of evaluations of trends and of cause-and-effect relationships, much insight can be gained of the problem and more intelligent choices and decisions can be made.

To demonstrate the effect of a change in objective and constraint, an example alternative is suggested wherein the objective is to minimize the probability of proliferation and the constraint is to reprocess spent fuel. It is felt that these choices differ from those of the White House, for example. It is believed that the results show that there are additional possible solutions to the problem not presently discussed, which meet the needs of those affected by the solution.

The existence of weapons-grade plutonium within government reservations and the proximity of potential spent-fuel processing facilities to those government reservations suggests a logical approach to plutonium management. The Savannah River Plant, located in Aiken, S.C. and operated by DuPont, is one of the locations where weapons grade plutonium is produced. Immediately adjacent to the Savannah River Plant is located the Barnwell Reprocessing Plant. The government fence, that now isolates the Savannah River Plant, follows the back side of the Barnwell facility. The Barnwell Plant was designed to reprocess commercial reactor spent fuel and to deliver the uranium and plutonium values back to the utility. The effort to move the present government fence to include the Barnwell Plant within the Savannah River reservation would be insignificant. The effort required to convince the group, who now intend the Barnwell facility to be a private enterprise, to operate the facility at fixed fee for the government would be greater.

The spent fuel from the utility would be delivered within the government fence. After reprocessing, the uranium values would be returned to the utility and the inferior weapons-grade plutonium would be retained within the fence along with the existing specially produced high grade plutonium for nuclear weapons. To make up for the retention of potential energy producing material, the government could return to the utility an energy-equivalent in uranium from government stockpiles that now exist (14). Recent government policy has been to eliminate some of these stockpiles, essentially by increasing the enrichment of the waste stream from enrichment plants (15). This portion of the example scenario suggests that instead of reducing the stockpiles to waste that they be transferred to the utility to produce energy in return for the plutonium to be retained for the foreseeable future at the reprocessing plant.

The total example scenario could well be naive in that all constraints and goals of the problem may not be adequately represented. For example, there are undoubtedly other demands on the uranium stockpile, such as the working inventory for new enrichment plants. However, possibilities and directions are obtained through this scenario that indicate that not all potential solutions are being discussed and that the alternatives being presented to the public are also naive. Together with the provision to the utility companies of energy equivalent enriched uranium from the existing stockpiles, replacing the plutonium, this policy will 1) reduce the enriched uranium stockpile, 2) relieve the pressure on spent-fuel storage basins, 3) constitute an active program under which adequate supplies of fissile materials are assured for the future, 4) maintain the breeder option open, and 5) delay the commercial use of plutonium fuel. Thus, placing the government exclusion fence around the reprocessing facilities, and balancing technical, environmental, and foreign policy assessments leads to a reversal in the choice of spent-fuel management policy. Intelligent assessment is necessary, all constraints should be considered, and in the case of the government fence, an ignored constraint results in a reversal of present spent-fuel management decision.

References

1. Beckurts, K. H. and K. Wirtz, Neutron Physics, Springer-Verlag, Berlin, 1964.
2. Stetson, N., U.S. ERDA Savannah River Operations Office, personal communication, September 1977.
3. Hubbert, M. K., "Survey of World Energy Resources", Canadian Mining and Metallurgical Bulletin, Vol. 66, No. 735, (July 1973), pp. 37-54.
4. Atlantic Council of the United States, Policy Papers: Nuclear Fuels Policy, Report of the Nuclear Fuels Working Group, Washington, D.C., 1976.
5. Kurstedt, H. A., Jr., J. A. Nachlas and J. R. Lyons, "An Analysis of Time Dependent Inventory Levels of Fabricated Nuclear Fuel", Trans. Am. Nucl. Soc., Vol. 23, June 1976, p. 589.
6. DePorter, E. L., J. A. Nachlas and H. A. Kurstedt, Jr., "Determination of Optimal Composition of Nondeliverable Fabrication Plant Fuel Material", Trans. Am. Nucl. Soc., Vol. 25, June 1977, in press.
7. Nachlas, J. A., H. A. Kurstedt, Jr. and G. J. Taylor, "Application of Linear Programming to Evaluate Nuclear Fuel Acquisition Alternatives", Proceedings of the First International Conference on Mathematical Modeling, Saint Louis, Mo., September 1977, in press.
8. Kurstedt, H. A., Jr., J. A. Nachlas and P. S. Kurstedt, "The Impact of Management Analyses on the Nuclear Energy Alternative", Proceedings of the Alternative Energy Sources: A National Symposium, December 1977, in press.
9. Nachlas, J. A., H. A. Kurstedt, Jr. and V. Macek, "Optimization of Spent Fuel Storage", Trans. Am. Nucl. Soc., Vol. 24, November 1976, p. 231.
10. Nachlas, J. A., H. A. Kurstedt, Jr., D. W. Swindle, Jr. and K. W. Korcz, "Modeling the Optimal Management of Spent Nuclear Fuel", Proceedings of the Eighth Annual Pittsburgh Conference on Modeling and Simulation, April 1977, in press.
11. Kurstedt, H. A., Jr., J. A. Nachlas and N. H. Bethel, "Modeling the Allocation of Spent Nuclear Fuel Transport Casks", Proceedings of the 14th Annual Meeting of the Southeastern Regional Chapter of the Institute of Management Sciences, 1977, in press.
12. Nachlas, J. A., H. A. Kurstedt, Jr. and J. R. Lorber, "An Optimal Set of Selected Uranium Enrichments Which Minimizes Blending Consequences", Nuclear Technology, December 1977, in press.

13. Nuclear Power Growth 1974-2000, WASH-1139, U.S. Atomic Energy Commission, Washington, D.C., 1974.

14. Parks, J. W. and D. C. Thomas, "Plan for Operating Enrichment Plants and the Effect on Uranium Supply", Division of Nuclear Fuel Cycle, U.S. ERDA, October 1976.

15. "Reactor Fuel Outlook", Nuclear Industry, Vol. 22, No. 7, July 1975, p. 3.