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S. E. Patton
E. J. Hanrahan
C. E. Bradley

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# SELECTION OF A MANAGEMENT STRATEGY FOR DEPLETED URANIUM HEXAFLUORIDE

S. E. Patton[1], E. J. Hanrahan[2], and C. E. Bradley, Jr.[3,4]

Lawrence Livermore National Laboratory, Livermore, California, USA
MACTEC, Germantown, Maryland, USA
United States Department of Energy, Germantown, Maryland, USA

## I. INTRODUCTION

A consequence of the uranium enrichment process used in the United States (U.S.) is the accumulation of a significant amount of depleted uranium hexafluoride ($UF_6$). Currently, approximately 560,000 metric tons of the material are stored at three different sites. The U.S. Department of Energy (DOE) has recently initiated a program to consider alternative strategies for the cost-effective and environmentally safe long-term management of this inventory of depleted $UF_6$. The program involves a technology and engineering assessment of proposed management options (use/reuse, conversion, storage, or disposal) and an analysis of the potential environmental impacts and life-cycle costs of alternative management strategies. The information obtained from the studies will be used by the DOE to select a preferred long-term management strategy.

The selection and implementation of a management strategy will involve consideration of a number of important issues such as environmental, health, and safety effects; the balancing of risks versus costs in a context of reduced government spending; socioeconomic implications, including effects on the domestic and international uranium industry; the technical status of proposed uses or technologies; and public involvement in the decision making process. Because of its provisions for considering a wide range of relevant issues and involving the public, this program has become a model for future DOE materials disposition programs.

This paper presents an overview of the Depleted Uranium Hexafluoride Management Program. Technical findings of the program to date are presented, and major issues involved in selecting and implementing a management strategy are discussed.

## II. DEPLETED URANIUM INVENTORY IN THE UNITED STATES

The uranium enrichment process used in the United States is called gaseous diffusion, which was first developed at the DOE Oak Ridge Reservation in Tennessee in the 1940s. In the 1950s, two more plants were added, one at Paducah, Kentucky, and one at Portsmouth, Ohio. All diffusion operations at the Oak Ridge plant ceased in 1985 due to a decrease in the need for enrichment services. In 1992, in response to the reduced requirements of defense programs, the production of highly enriched uranium at Portsmouth was discontinued. On 01 July 1993, general responsibility for uranium enrichment in the United States was transferred from the DOE to the United States Enrichment Corporation.

[1] Lawrence Livermore National Laboratory, 7000 East Ave., P.O. Box 808, L-197, Livermore, CA 94551, USA.
[2] MACTEC, 19512 Amaranth Dr., Suite C/D, Germantown, MD 20874, USA.
[3] U.S. DOE, Office of Uranium Programs, Facility and Technology Management Division, NE-33, 19901 Germantown Road, Germantown, MD 20874, USA.
[4] Inquiries concerning the material presented in this paper should be addressed to: Mr. Charles E. Bradley, Jr.

A major consequence of the gaseous diffusion process is the accumulation of a significant amount of depleted $UF_6$ containing between 0.2 and 0.4 weight percent of uranium-235. By 01 July 1993, approximately 560,000 metric tons had accumulated at the three gaseous diffusion plant sites. The depleted $UF_6$ is stored in large steel cylinders holding 10 to 14 tons each, stacked two layers high, in large outdoor yards. The depleted $UF_6$ occupies a total of about 47,000 cylinders: approximately 29,000 cylinders at Paducah, 13,000 at Portsmouth, and 5,000 at Oak Ridge.

The DOE is responsible for safely storing and managing this depleted $UF_6$. Current management activities include regular inspection of cylinders, corrective maintenance of storage areas, and replacing or refurbishing cylinders as needed. The existing program calls for the safe storage of the material until the year 2020, when the cylinders begin to reach the end of their normal life. At that time, conversion of the depleted $UF_6$ to $U_3O_8$ would begin. If it is determined that the depleted $UF_6$ is no longer needed, action would be taken to dispose of the material.

## III. OVERVIEW OF THE DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT PROGRAM

The DOE is currently reassessing its management plan for the depleted $UF_6$. This decision arises from various domestic and international developments, including the changed mission and functions of DOE programs for nuclear materials production and research; changes brought about by the end of the Cold War; the shift in emphasis mandated by Presidential budget requests; and directives of the Secretary of Energy to reconsider the Department's future mission, functions, and responsibilities. The unique properties of depleted $UF_6$, as well as the large volumes in storage, suggest that a thorough evaluation and analysis be conducted before decisions on long-term disposition are made. The DOE has therefore initiated a program to consider alternative strategies for the cost-efficient and environmentally safe long-term management of the material, called the Depleted Uranium Hexafluoride Management Program (henceforth referred to as the Program).

The Program consists of two phases. The first phase, management strategy selection, was initiated November 1994 and will culminate with the selection of a preferred long-term management strategy. The activities in this phase include an engineering analysis, an assessment of environmental impacts, and a life-cycle cost analysis of several alternative management strategies. The long-term strategy will be documented in a Record of Decision, which is planned to be issued in early 1998. The Program provides opportunities for public input to all parts of the selection process.

The second phase of the Program will be implementation of the management strategy. During this phase, the specific process(es) and the site(s) for conversion, manufacturing, reuse, storage, or disposal will be determined. It is likely that a request for proposals will be made by the DOE for specific technologies to be utilized in the management strategy.

### A. Engineering Analysis Project

The Engineering Analysis Project is a technology and engineering assessment of proposed uses and management technologies for the depleted $UF_6$. The Technology Assessment phase of the project will identify these uses and technologies and assess their technical feasibility. The DOE will use the findings of the technology assessment together with other factors in developing several alternative long-term management strategies. These alternative management strategies will be then assessed for environmental impacts and the life cycle costs.

The second part of the Engineering Analysis Project will provide a comprehensive technical analysis of the components of the alternative management strategies. This part of the project will provide the engineering data necessary to assess the environmental impacts and life-cycle costs of the alternative strategies. The analysis will include flowsheets and process descriptions, mass and energy balances, pre-conceptual facility design and layouts, regulatory analysis, and a preliminary description of hazards. The Engineering Analysis Project began in November 1994 and a report will be issued in April 1996.

### B. Environmental Impact Statement

The Environmental Impact Statement will assess the potential environmental impacts of the alternative management strategies. The assessment will consider the impacts of siting potential facilities and the transportation of materials to and from such facilities. An Advanced Notice of Intent to prepare an Environmental Impact Statement was published in the *Federal Register* on 10 November 1994 (59FR56325). Preparation of the Environmental Impact Statement is scheduled to begin in January 1996 and be completed in October 1997.

### C. Cost Analysis Project

The Cost Analysis Project will estimate the life-cycle costs of the management strategies being considered. Estimated costs will include a breakdown for capital, operations and maintenance, waste processing and disposal, decommissioning, and environmental restoration. Parametric analysis will include variations to time/schedule, escalation and discount rates, disposal costs, and throughput. The Cost Analysis Project is scheduled to begin in October 1995 and be completed by January 1997.

### D. Public Participation

The Program will provide multiple opportunities for public participation in the decision making process, as required by U.S. DOE policy and congressional mandate. As part of the effort to secure early involvement, the public was included in the invitation to recommend uses and management technologies for the depleted $UF_6$, the first step in the overall Program. The public will be involved in the scoping process which will determine which management strategies will be assessed for environmental impacts and life-cycle costs. The public will also be asked to review and comment on the Environmental Impact Statement.

## IV. SUMMARY OF THE TECHNOLOGY ASSESSMENT

The first part of the Program, the Technology Assessment, has been completed and the findings were recently published in a report. On 10 November 1994, the U.S. DOE published a *Federal Register* notice (59FR56324) requesting recommendations from interested persons, industry, and other Government agencies for potential uses for the depleted $UF_6$ and for technologies that could facilitate the long-term management of the material. Specifically, recommendations were requested for the following: (1) uses for or applications of products or materials that include any form of depleted uranium and (2) technologies that could facilitate the long-term management of depleted uranium. The uses or applications could be for depleted uranium in its current chemical form ($UF_6$); for any of its individual components; for either the uranium or the fluorine in some other chemical or physical form; or for products made from any form or compound of depleted $UF_6$, including alloys, cements, or other materials.

The submittals were reviewed by five independent experts (i.e., technical experts who were free of any real or perceived conflict of interest with the assignment). In addition to providing an assessment of the technical feasibility of each recommendation, the review also identified the benefits and drawbacks associated with each proposed use or management technology, any noteworthy points that would not be evident to non-experts, and any issues that might be relevant to the application of the use or technology.

Evaluation factors were developed to give the reviewers a sense of what issues were important to the DOE in ultimately defining reasonable alternative management strategies. Draft evaluation factors were prepared by a national laboratory and presented to the public for comment. The evaluation factors identified issues pertaining to (1) environment, safety, and health; (2) waste management; (3) costs; (4) technical maturity; and (5) socioeconomics. The reviewers were to address each factor in their assessments. They were also asked to provide (1) any other pertinent information and (2) an overall conclusion as to the technical feasibility of the recommendation.

In all, 57 responses were reviewed in the Technology Assessment. A number of the responses contained more than one recommendation, resulting in a total of 70 separate recommendations with some duplication. The assessment began 30 January 1994 and was completed on 30 April 1995. It was documented in the *Depleted Uranium Hexafluoride Management Program Technology Assessment Report for the Long-Term Management of Depleted Uranium Hexafluoride* (Zoller et al. 1995), published on 30 June 1995.

## V. TECHNICAL FINDINGS TO DATE

The majority of the recommendations received were determined by the reviewers to be technically feasible. Only six were determined to be technically infeasible, and several were considered feasible with qualifications. The recommendations were arranged into four general categories (Table 1): conversion, storage, recycle/reuse, and disposal.

Responses to the *Federal Register* notice recommended conversion of the depleted $UF_6$ to oxide forms (triuranium octaoxide [$U_3O_8$], uranium dioxide [$UO_2$], and uranium trioxide [$UO_3$]); uranium metal; and uranium carbide (UC, $UC_2$). Specific responses for the conversion to $U_3O_8$ included a process for defluorination with hydrofluoric acid by-product, a process for defluorination with anhydrous fluoride by-product, and a process for defluorination with anhydrous hydrogen fluoride by-product with the concurrent production of hydrofluorocarbons. Both conventional "wet" and "dry" processes for conversion to $UO_2$ were recommended. Recommendations for the conversion to metal included the standard industrial batch metallothermic reduction (Ames) process and a direct reduction plasma process.

Storage recommendations were defined by the type of storage facilities and the chemical form of the stored material. The generic types of storage facility recommended were outside yards, buildings, and vaults. The recommended forms for the stored material were $UF_6$, $U_3O_8$, $UO_2$ (ceramic), and uranium metal.

The principal suggested use or recycle recommendations can be grouped into several categories. One group included the use of the uranium metal in dense material applications (e.g., armor piercing munitions). Using the material for re-enrichment (e.g., blending, centrifuge, and atomic vapor laser isotope separation) would require the $UF_6$ form or a metal conversion. The metal or the oxide forms could also be used in radiation shielding applications or as a fuel for an advanced reactor.

Recommendations for disposal were defined by the uranium chemical form, the waste form, and the characteristics of the disposal site. The principal chemical forms included the oxides ($U_3O_8$ and $UO_2$) and metal. The material would be containerized, encapsulated, vitrified, or disposed of in bulk form. Recommended disposal sites included mined geologic formations or existing underground mines.

## VI. PRELIMINARY MANAGEMENT STRATEGIES

At the beginning of the Program, DOE identified a preliminary list of four general strategies for management of the depleted $UF_6$: (1) continuation of current strategy and management practices; (2) modification of current depleted $UF_6$ storage facilities and procedures; (3) use of depleted $UF_6$; and (4) disposal of depleted $UF_6$. This list was published in the *Federal Register* (59FR56324) in the advanced notice of intent to prepare an Environmental Impact Statement. These general strategies will be expanded and modified by DOE into alternative management strategies by taking into consideration the findings of the Technology Assessment and the results of internal and public scoping processes. At this time, the DOE has no preferred strategy and will consider all reasonable strategies.

The first strategy, the continuation of current storage and management practices, would continue present activities at the three enrichment facilities until 2020 or until shutdown and decommissioning of the sites. This would include regular inspection of the cylinders; replacement/refurbishment of deteriorating cylinders, as necessary; technical assessments of cylinder performance and development of improved inspection methods; and research on coatings to control corrosion of cylinder surfaces. The goal of the management practices is to ensure the safety of workers, the public, and the environment.

The second strategy, modifying storage facilities and procedures, would include significant changes in the facilities and management procedures for the depleted $UF_6$. Such changes could consist of (1) redesign of the storage yards, (2) construction of storage buildings in lieu of outdoor storage, (3) provision of increasing cylinder wall thickness (e.g., double-walled containers), and (4) increased inspection frequency.

The third strategy, use or reuse, consists of various options involving conversion of the material. End products of the conversion process include oxides, metal, uranium concrete, and uranium carbides (ceramics). Uses of the converted depleted $UF_6$ would include (1) use as radiation shielding in the management of nuclear materials, including high level radioactive waste and spent nuclear fuel, and (2) use in armament manufacture.

The fourth strategy, disposal, would include disposal of the material either in its present form or in other forms, at appropriate waste disposal sites. Possible locations for disposal and the amount of material to be disposed would be considered in this alternative.

## VII. ISSUES RELEVANT TO SELECTING A MANAGEMENT STRATEGY

The selection of a long-term management strategy will be documented in a Record of Decision issued by the DOE Secretary of Energy. This Record of Decision will be based, *inter alia*, on the Environmental Impact Statement and the Cost Analysis Project and will provide the rationale for the management strategy selection. As with any U.S. governmental strategy decision on a program of this magnitude, important public policy issues must be considered. Following is a brief discussion of some of these issues.

A. Technical Status

Technical maturity is an important consideration. A long and expensive research and development program would reduce the attractiveness of a use or management technology, even one with a high probability of achieving the development goals. Similarly, a technology with potential high efficiency and low cost but with a low probability of development success might present an unacceptable program risk. The timing of use and disposal actions will have a significant impact on the technologies that can be used. If near-term actions are required, then current technological practice will have to be used. If actions are not required for many years, then evolving technologies can be considered.

The public's view of the technology is also an important factor. The public, or at least some portions of the public, are sensitive about certain technologies, such as the fast breeder reactor. A technology that involves plutonium would raise serious public concerns. Also, it would be difficult to gain acceptance for a technology associated with a facility that the public considered a threat to health and safety.

This is not to say that technical characteristics are unimportant. Key to the selection of any technology is the amount of depleted uranium that would be used; the rate of use or processing; the facilities, equipment, other materials, and labor required; wastes and other environmental discharges; hazards; and regulatory requirements. All of these issues are addressed in the *Technology Assessment Report.*

B. Environment, Safety, and Health

The DOE's selection process must include environmental, safety, and health effects for the total program. Consideration of the impacts of conversion, storage, recycle/reuse and disposal of the material is necessary, but not sufficient. The activities prior to these options and the outputs must also be considered. It is anticipated that the management strategy will require continued storage of the depleted $UF_6$ at the current sites for some period of time, and the impacts of such storage must be included in the decision making.

In short, a cradle-to-grave assessment is required. Inherent in such an assessment is the evaluation of total effects, which include any development related to the technology options, pre-existing development at or in the vicinity of the site, and the impacts following disposal.

C. Economic Implications

Depleted $UF_6$ has economic value. Therefore, uses for the material should be seriously considered in selecting a management strategy.

Since the strategy selected may prevent other uses of the material in the future, lost opportunity costs will be considered. For example, irretrievable disposal would preclude the use of depleted uranium as shielding for high level radioactive waste. Also, early actions may sacrifice the opportunity to use cheaper, more efficient technology that requires development.

The full life-cycle cost of the management strategies will be evaluated. Full life-cycle includes all costs from today through costs following ultimate disposition. Cost savings from depleted uranium uses should be balanced against the cost of processing, fabrication, and disposal of the product. All the costs to the Federal government must be included in the cost evaluation.

## D. Public Involvement

The public is highly sensitive to environmental risks in general and to nuclear or radiation risks in particular. Any long-term management strategy for depleted $UF_6$ will involve one or more of the following: processing, use, transportation, storage, and disposal. Siting facilities is difficult, as U.S. experience in siting waste management facilities for nuclear materials and other nuclear facilities has shown.

A respondent to the Request for Recommendations identified public acceptance as a key factor in siting considerations and noted that "a widely supported site selection strategy would be of fundamental importance to the overall success of the program." However, public involvement will not be limited to siting actions. The DOE has already held several public meetings near each of the gaseous diffusion plants to explain the program and receive public comments. These meetings will continue throughout the Program.

Public involvement is an essential part in preparing an Environmental Impact Statement for the selection of a strategy for the long-term management of depleted uranium hexafluoride. Public meetings will be held to receive input on the scope of the Environmental Impact Statement. Written comments will be solicited and public meetings held to receive comments on the draft Statement. The siting and construction of any facilities required to implement the selected strategy will require the preparation of further environmental impact analysis with concomitant public involvement.

## E. Socioeconomic Factors

Whenever conversion, fabrication, use, or disposal facilities are sited, they will have socioeconomic impacts. The potential impacts include increased population, increased transportation requirements, possible change in local character due to the influx of new people and businesses, increased tax base, increased job opportunities, and investments in infrastructure and other programs by state and local governments. The implementation of the long-term management strategy should seek to minimize the undesirable socioeconomic impacts and maximize the desirable ones.

## F. Public and Private Sector Roles

There are many ways in which the public and private sectors can work together in achieving an efficient and effective program. Government procurement regulations allow for a number of contract structures for involving the private sector. The selection of public or private ownership for one or more elements of the long-term strategy will also affect the economics of the cost, in particular the need for government appropriations. The DOE expects that the private sector will play a major role in the long-term management of depleted $UF_6$.

# VIII. CONCLUSIONS

The U.S. DOE has initiated a program to consider alternative strategies for the cost-effective and environmentally safe long-term management of its inventory of approximately 560,000 metric tons of depleted $UF_6$. The program involves a technology and engineering assessment of proposed management options (use/reuse, conversion, storage, or disposal) for the material and a subsequent analysis of the potential environmental, health and safety impacts and life-cycle costs of alternative management strategies. The program also has provisions for considering a wide range of issues and involving the public in the decision making. This program has become a model for future DOE materials disposition programs.

As this paper has shown, a number of the key issues related to the decision are already being addressed. Two additional issues have recently been identified that will have to be considered in the selection and implementation of a long-term management strategy for depleted $UF_6$:
(1) current trends for reducing government spending will focus more attention on the balance of life-cycle costs versus health and environmental impacts; and (2) the selection decision may have effects on the domestic and international uranium industry. However, prompt identification of issues and early involvement of the public in the decision making process will help to ensure the ultimate selection of an appropriate and acceptable management strategy.

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**TABLE 1**

**Recommended Uses and Technologies for Consideration in Selecting a Management Strategy for Depleted Uranium Hexafluoride**

| CATEGORY | RECOMMENDATION |
|---|---|
| CONVERSION | Oxide |
| | Metal |
| | Carbide |
| STORAGE | $UF_6$ |
| | Oxide |
| | Metal |
| RECYCLE/REUSE | Dense Material Applications |
| | Re-enrichment (AVLIS, Centrifuge, Refeed/Blending) |
| | Shielding |
| | Advance fuel cycle (LWR, MOX, FBR, IFR, Pu) |
| DISPOSAL | Oxide |
| | Metal |

## REFERENCES

U.S. *Federal Register* Notices (59FR56324), "Management of Depleted Uranium Hexafluoride ($UF_6$); Requests for Recommendations," Vol. 59, No. 217, 10 November 1994, page 56324.

U.S. *Federal Register* Notices (59FR56325), "Alternative Strategies for the Long-Term Management of Depleted Uranium Hexafluoride Resources at Several Geographic Locations," Vol. 59, No. 217, 10 November 1994, page 56325.

Zoller, J.N., R.S. Rosen, M.A. Holliday, and S.E. Patton. *Depleted Uranium Hexafluoride Management Program - The Technology Assessment Report for the Long-Term Management of Depleted Uranium Hexafluoride*, Volumes I and II (UCRL-AR-120372). Lawrence Livermore National Laboratory, Livermore, California, USA, 30 June 1995.

# BIOGRAPHIES

## Scott E. Patton

Mr. Patton is a biophysicist with over 15 years' experience in the field of radioecology and environmental toxicology. His research experience includes determining secondary contamination from the Chernobyl nuclear accident and assessing residual environmental contamination from nuclear weapons testing. Recently, he has been involved with environmental and waste management issues related to the gaseous diffusion process for uranium enrichment. He is presently managing the technical projects associated with the disposition of depleted uranium hexafluoride.

## Charles E. Bradley, Jr.

Mr. Bradley is an environmental manager with the Department of Energy, and has worked in environmental compliance and regulation for 25 years. He has been the environmental manager for the Department's uranium enrichment plants, and previously worked on the Department's high-level nuclear waste repository program. Prior to government service, he worked as a consultant in environmental and land use planning. Currently, he manages the Department's long-term program for the management and disposition of depleted uranium hexafluoride.

## Edward J. Hanrahan

Mr. Hanrahan is a program manager with the MAC Technical Services Company. He is a nuclear engineer with over 35 years' experience. During his career in the Department of Energy, he was involved with the nuclear fuel cycle, particularly uranium and uranium enrichment. He was the Department's representative on the President's Task Force on the Chernobyl Accident.