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POSSIBLE APPLICATION OF LASER ISOTOPE SEPARATION

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16. ABSTRACT

Since the electromagnetic separation method was phased out in favor of the gaseous diffusion methodology, a continual search has been going on to find a more economical isotope enrichment process.

The gaseous diffusion process is very demanding in terms of capital investment. In addition to the cost of equipment, a large investment is required for materials. For example, large quantities of a heavier isotope (U^{238}) must be processed in order to have access to the desired lighter isotope (U^{235}). There is a tremendous cost in electrical power for operation. Also, there is a requirement that huge quantities of cooling water be accessible; this usually means location near a river, or other suitable water source.

Based on recent reports the development trend by the Energy Research and Development Administration (ERDA) is toward the latest in a series of innovations, the gas centrifuge. The centrifuge process depends on fast-spinning centrifuges to enrich the U^{235} isotope in the normal isotope, or U^{238}. Most of the technology surrounding this innovation is clouded in secrecy, which makes an estimate of its economic viability impossible.

As an alternative, there exists another method, the laser isotope separation process, which opens up the possibility of an isotope-separation process with the effectiveness of gaseous diffusion and gas centrifuge methods but at a much lower cost in terms of capital investment, inventory of materials in process, and operating costs for electrical power. This process is described herein.

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TECHNICAL MEMORANDUM X-64947

POSSIBLE APPLICATION OF LASER ISOTOPE SEPARATION

INTRODUCTION

Long before the laser was invented, the gaseous diffusion methodology was a mature technology, so it was quite natural that the investment in capital equipment was heavily on the side of gaseous diffusion. In the beginning, the demand for enriched fuel was principally to the national defense establishment with only a minute amount being used for research and development. Since that time the nuclear reactor (once only a laboratory toy) has evolved into a leading contender for generation of electrical power both inside the United States and throughout the world. Recently, the Tennessee Valley Authority (TVA) released information that fossil fuel for conventional power generating stations was approximately six times the cost of nuclear fuel (uranium). Also, the capital cost of fossil-fueled plants, with the additional cost of antipollution equipment, is almost equal to that of a nuclear plant. This would seem to underline the importance of this subject, in line with the steadily increasing costs of fossil fuels.

REASONS FOR PREFERENCE OF THE LASER ISOTOPE SEPARATION METHOD

As a contrast to the increases in cost of the fossil fuels, laser research is much more cost-effective in both space and capital equipment. No huge turbines, pressure vessels, or miles of piping are needed, and no source of cooling water (such as a river) is required. The research may be located almost anywhere there is sufficient laboratory space. There is no minimum size or quantity of materials-in-process, such as is, for example, in the gaseous diffusion process.

Separation Factor

The efficiency of the isotope separation process is higher than that of any other existing or proposed process based on the current state-of-the-art technology.

Amount of Feed to be Processed

For the gaseous diffusion method, the quantity of the materials-in-process is enormous, and the amount of the feed to be processed is directly proportional to the inventory of the system. Also, the energy costs are proportional to the amount of the feed, or materials-in-process. For all except the laser methodology, both the desired isotope and those unwanted isotopes with which it is mixed must be diffused, centrifuged, distilled, electrolyzed, or whatever, through the various stages of the cascade.

For the laser methodology only the desired isotope (usually U^{235}) is completely processed, i.e., irradiated sufficiently (by photochemical reaction) to enable it to be separated by either chemical or physical means. Power consumption, therefore, is directly proportional to the amount of product rather than to the volume of feed. This fundamental characteristic is extremely useful for situations where it is desired to separate an isotope of very small incidence percentiles, e.g., U^{235} (only 0.72 percent) from an isotope which is preponderant, U^{238} (over 99 percent). Needless to say, this latter characteristic will have a dominant influence on the aspect of power consumption, which is one of the reasons laser isotope separation is so attractive.

Selection of Desirable Isotope

With ordinary methods, it is not possible to pick a desirable isotope regardless of its weight, either light, medium, or heavy. With laser methods, it depends only on the absorption of light at a given wavelength and the knowledge of the precise wavelength at which the desired isotope absorbs the laser output energy, whether light, heavy, or intermediate. Instead of having to remove very large quantities of the heavy isotope, e.g., U^{238}, one merely separates out the small amount of the desired product, U^{235}, resulting in a large savings in energy.

Capability for Intermittent Operation

The capability for successful operation of the usual cascade process depends on a continuous day-in/day-out operation, a full 24 hours a day, 7 days a week. Such is the case in the gaseous diffusion staged-cascade operations. This, of course, increases the cost to operate, both from the standpoint of operations personnel as well as, again, the expenditure of electrical power.

As a consequence of the large separation factors with the relatively few stages, and small materials-in-process flows, intermittent operation could become tolerable. Of course, a major consideration would be that the capital cost of such a system is sufficiently small that the failure to utilize the equipment at full capacity all the time would not be economically and/or technically prohibitive. The savings in the use of off-peak power would offset the inefficiency of mixing streams of slightly different concentrations. Nevertheless, the capability to operate an isotope separation plant intermittently would certainly be a goal worth attempting.

STATEMENT OF PROBLEM/OBJECTIVE

The separation of isotopes by laser represents an opportunity for the Marshall Space Flight Center (MSFC)/Huntsville community to acquire a new industry, and as such would further add to the fine start the community already has on diversification of its industry. Several questions which would naturally surface are listed below with appropriate answers or comments:

1. Is this effort needed by the nation (or ERDA) in quest of either new energy sources and/or technologies in support of the overall energy problem?

Answer: This proposed activity definitely falls under the heading of new energy technology — to produce the necessary fuel for a nuclear power power plant. By 1983, the demand for enriched uranium for such plants is expected to exceed the capacity of the present gaseous diffusion facilities [1].

2. What is the economic and/or technical justification to do research in the field of laser isotope separation?

Answer: Both from the standpoint of economics and/or technology, the effort is justified. The extent of capital investment and consumption of electrical power is considered to be minimized with the laser methodology. From the technology viewpoint also, the separation factor is the highest of any of the several methods available, so a high level of enrichment can be achieved in a single pass through a laser device.

3. Can the Marshall Center qualify to perform research and development in the specific application of laser technology?

Answer: To quote Dr. Robert C. Seamans [2], "The Marshall Center has demonstrated its ability to manage complex technical programs and has unique facilities for chemical analysis, materials evaluation, vibration, thermal, and acoustic testing." Also MSFC has unique capabilities in the area of lasers as well as in the field of vacuum technology. Space is no problem since many empty buildings stand ready for use, and they could be secured separately if necessary. MSFC also has unique experience in the field of economic and business skills which also can be relied upon for cost and economic analysis of special projects. Several persons at MSFC have specific experience in the isotope separation field.

DESCRIPTION OF PROPOSED METHOD TO SEPARATE ISOTOPES

The technique which is described here will, in general, describe the methodology to separate the desired isotope from its parent mix, whatever that source may be. The isotope U^{235} will be used as a model for purposes of description, although admittedly it is at present the primary source of interest. The isotope to be separated might just as well have been one of mercury, lithium, or carbon.

The key to this method basically is the variable frequency laser, which can be tuned to adjust its wavelength over a broad spectral range from 2500 Å to 10 000 Å. The principle for this branch of technology is the dye laser. To cover the whole visible range, different dyes are used to construct the laser, each one covering just a few angstroms bandwidth [3]. Also inherent to this method is the use of the CO_2 laser, which is used in conjunction with the tunable dye laser, to bring the energy level of the desired isotope up to the ionization continuum and beyond. The isotope which is selected for separation can thus be effected by a charged collector plate (to attract the ionized atoms of the desired isotope).

To present a summary of a system to separate isotopes, the process for separation of U^{235} is outlined. In general, this methodology may be applied to any element that contains two or more isotopes which have half-lives of a significant length.

The process is outlined by three steps:

1. Atomization — In this initial step, the metallic uranium is converted to gaseous form by a suitable vacuum furnace and with a suitable inert gas atmosphere. For those elements that occur naturally in the atomic form, this step is not required.

2. Irradiation — This phase is accomplished in steps utilizing three lasers. The first two are dye lasers to raise the energy level of the atoms of uranimum first to about 24 000 cm^{-1}, and then with the second dye laser up to around 25 000 cm^{-1}, or just under the ionization level (preferably about 900 cm^{-1} below the ionization level). The third laser is a CO_2 (infrared) laser with a wavelength that will effectively ionize the U^{235} atoms, with a power in the vicinity of 50 kW.

3. Ionization — The energized atoms of uranium U^{235}, each of which emits an electron to become an ion, are collected on a charged electric collector plate (about 10 kW). As a part of this working procedure, the bandwidth of the lasers should be narrow enough that only the U^{235} atoms and not U^{238} are excited. The atoms of U^{238} are collected separately on a collector plate [4].

Whether by direct separation through the action of the laser acting on the metallic form of uranium, or by virtue of enhancing the formation of a chemical compound, the laser is a very efficient tool in the field of isotope enrichment.

DISCUSSION

There have been many discussions concerning the logic of enlarging our present capacity of enrichment plants (gaseous diffusion plants). The present capacity is around 17 million SWU* per year, and the projected increase to about 23 million SWU per year by 1980 [5]. A further expansion effort, the Cascade Upgrading Program (CUP), which will increase the capacity to 28 million SWU per year is scheduled for completion by 1983 and will require additional power supplies of about 1300 MWe. A new plant of the gaseous diffusion variety will cost about $2 billion and must have power supplies of around 2500 MWe.

Uranium enrichment, currently a sole government monopoly under the ERDA, will have to be greatly expanded to meet anticipated civilian needs. Uranium enrichment is projected to emerge as an entirely new private enterprise venture with a capitalization of at least $5 billion by 1985 [5]. This value is, of course, based on the presumption of gaseous diffusion technology and/or gas centrifuge. For some reason, no mention has been made of the subject laser methodology, but it is probable that the cost estimates for both the separation facility as well as the necessary electric power utility will be considerably less.

*An SWU is a separative work unit, not a physical quantity. It defines the size of the enrichment plant.

With the above statements of fact, it would appear logical that a laser isotope separation would at least become a bona fide candidate. The freedom from having to locate near a body of cooling water would, of course, become a consideration. Also a laser separation facility could be sized to meet the required capacity with no minimum or maximum size constraint. To illustrate the flexibility of the laser methodology, characteristics of the gaseous diffusion and laser methods are given in Table 1.

TABLE 1. COMPARISON OF GASEOUS DIFFUSION AND LASER METHODS

Characteristic	Gaseous Diffusion	Laser Method
Separation Factor	Small	Large
Amount of Feed to be Processed	All	Only Amount Proportional to Isotope Desired
Choice of Desired Isotope	Light Isotope Only (U^{235})	Any
Capability of Intermittent Operation	No	Yes

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Based on the information contained herein, there can be little doubt concerning the economic justification for separation of isotopes by laser. For aerospace applications alone or wtih shuttle or satellite in stationary orbit, a savings in weight of 1 pound is worth $ 1000. For a shuttle which is to go into near-earth orbit between 100 and 500 times, a pound saved is worth somewhere between $ 10 000 and $ 50 000 [6]. The separation of light isotopes (especially titanium) would seem to be the most promising application for laser-isotope separation.

2. The use of lasers in chemistry opens up a new field — the chemistry of molecules in highly vibrationally excited conditions. This field is potentially of great practical significance: In principle it holds forth the promise of selectively controlled chemical reactions, economy of energy consumption, and high reaction rates [7]. In vibrationally excited molecules, it is the bond which makes the principal contribution to the excited normal vibration and which becomes chemically active.

3. Whether by virtue of photochemical action on a molecule or by reaction of the laser beam on specific atoms of a metal, the laser remains a unique tool to selectively energize and subsequently separate the desired isotopes of an element. The outlay of capital equipment and overall size of the system will most certainly be reduced significantly over the gaseous diffusion and gas centrifuge methods. An additional feature is the all-important reduction in electrical power consumption.

Recommendations

1. A feasibility study, at least, is recommended to determine if the process can be implemented by the MSFC complex, with the expertise of laser technology, vacuum technology, and general availability of technical management, physical, engineering and chemical disciplines.

2. With the promise of across-the-board savings in energy, as well as in captial expenditures, it would appear reasonable for ERDA to be made aware of the MSFC capabilities.

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APPROVAL

POSSIBLE APPLICATION OF LASER ISOTOPE SEPARATION

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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