Book Review

Uranium Enrichment. Edited by S. Villani, Springer-Verlag New York, Inc. (1979). 322 pp. $49.00.

Uranium Enrichment opens with an introductory chapter by the editor, which describes the role of enrichment in the nuclear fuel cycle and summarizes the development status of the processes to be described in later chapters. The second chapter, by B. Brigoli, develops the theory of cascades applicable to all separation processes. The five subsequent chapters are monographs, some brief, by different authors, describing particular aspects of five enrichment methods: gaseous diffusion, centrifugation, separation nozzle, laser methods, and plasma-separating effects.

Because of their diverse authorship, these chapters differ considerably in style, terminology, and completeness of coverage. The excellent chapters on gaseous diffusion and centrifugation suffer somewhat from security restrictions and lack of tables defining symbols. Overall, nevertheless, this book is the most complete, up-to-date, and authoritative publication on uranium enrichment in the open literature. It should be in the library of everyone interested in uranium isotope separation.

Chapter 1 sketches the anticipated growth of nuclear power and projects the future demand for separative work. A brief description is then given of the principal enrichment processes now at the industrial or demonstration plant stage–gaseous diffusion, the gas centrifuge, and aerodynamic processes. Finally three processes that are less fully developed–laser-based, chemical exchange, and electromagnetic–are mentioned. The first chapter is a clear and informative introduction to uranium isotope separation.

Chapter 2, "Cascade Theory," provides an introduction to the principles applicable to all isotope-separation processes. Standard equations are derived for the number of stages at total reflux, the minimum reflux ratio, and the number of stages and total flow rate in an ideal symmetric cascade. Separation potential and separative work are shown to be natural measures of the magnitude of a job of separation. Square, squared-off, and nonsymmetric cascades are also treated, as are equilibrium time and optimum stripping. This chapter thus provides a good introduction to concepts to be given practical application in later chapters. A few misstatements and typographical errors in the section on equilibrium time reduce the value of that section.

Chapter 3, "Gaseous Diffusion," by D. Massignon, is the most detailed complete monograph on this process in the open literature. The author, one of the leading engineers in French uranium enrichment programs, has drawn extensively on his personal participation in French work and on published accounts of U.S. developments. This chapter opens with a brief history of the gaseous diffusion process. Then separation of gas mixtures by molecular effusion is dealt with at length. Equations are given for the separation efficiency and specific flow rate predicted by several diffusion barrier models, and a comparison is made of theory with the limited published experimental data. Next the factors affecting the separation efficiency of a diffusion stage are dealt with in detail. Expressions are derived for the effect of pressure and other operating variables on such stage characteristics as separation factor, separative capacity, barrier area, and power consumption. Properties of UF_6 are described in sufficient detail to understand its effect on plant design. Then individual plant components are taken up: barrier, diffusers, compressors, coolers, inert gas purging systems, UF_6 feed and product systems, and construction materials. These sections are excellent.

The next section, on economics and the design of a gaseous diffusion plant, is less informative. The complex aspects of diffusion plant costs and design optimizations are not readily explained in a few pages. The chapter closes with a good, concise description of U.S. and French diffusion plants, covering existing plants, their planned expansion, and design studies of possible future plants. In addition to its excellent description of the gaseous diffusion process, this well-written chapter also conveys an appreciation of the ingenuity with which the developers of the gaseous diffusion process have solved the many problems of this difficult technology.

Chapter 4, "Centrifugation," by the French authority Soubbaramayer, gives a brief, but informative, history of uranium isotope separation by the gas centrifuge and an explanation of the principles by which separation is effected. The remainder of this chapter is an authoritative summary of the theory of the separation performance of the countercurrent gas centrifuge. Section 4.2 describes the hydrodynamics of gas flow in strong centrifugal fields. Here, the author has performed a notable service in summarizing the results of many recent increasingly accurate solutions for flow patterns in a gas centrifuge. Section 4.3 derives equations for the composition distribution and separation performance of a centrifuge from the flow fields obtained in Sec. 4.2. Examples are given of the separation factor and separative power for each of the principal means for establishing countercurrent flow and for an optimum combination of these drives. This elegant summary of a large amount of theoretical and numerical work is especially impressive. The concluding Sec. 4.4 gives a good, concise summary of the present status of centrifuge theory. Numerous references to recent work tell where to find details of the theoretical developments so well summarized in this chapter. This chapter explicitly excludes discussion of the design of actual centrifuges, the materials of which they are made, their operating characteristics, or their separation performance.

Chapter 5, "Separation Nozzle," by E. W. Becker, is a summary of work done by the author and his German colleagues in developing the aerodynamic process for enriching uranium, which is to be used in a 200 000 kg SWU/yr pilot plant being built in Brazil. In this process, a mixture of 4 mol% UF_6 and 96 mol% hydrogen is accelerated to supersonic speed by flow through a convergent-divergent slit and then caused to flow through a semicircular groove. The centrifugal force field in the groove causes UF_6 depleted in $^{235}UF_6$ to concentrate near the wall. Stage enrichment factors three or four times those of gaseous diffusion have been obtained, with power consumption about the same as gaseous diffusion for the same separative capacity.

The chapter starts with a short history of aerodynamic processes, with passing mention of a competing process under development in South Africa. The theory of separation in a fast-moving, curved flow stream is then summarized with examples of the separation performance of nozzle systems. Brief descriptions are given of several types of nozzle separating units and of compressors, cold traps, and other equipment to handle mixtures of hydrogen and UF_6. This chapter provides an excellent summary of the notable work done by the author and his associates in developing their nozzle process with many references. Inclusion of more of the published information on the similar aerodynamic process being developed in South Africa would have been appropriate.

The narrow line width, high efficiency, spatial coherence, and tunability of lasers make processes using these light sources of great potential value for separating uranium isotopes. In Chap. 6, "Laser Methods of Uranium Isotope Separation," C. P. Robinson and R. J. Jensen list the requirements of an economic laser-based isotope separation process and cite numerous examples of elements other than uranium whose isotopes have been separated in this way. Reference is also made to published work in which milligram quantities of uranium isotopes have been separated by laser means. Descriptions are given of the two principal laser-based processes being investigated for separating uranium isotopes. The atomic vapor method, pursued by Avco-Everett Research Laboratories, Exxon Nuclear Co., Lawrence Livermore Laboratory, and the Soviet Union, uses selective photoionization of ^{235}U atoms in uranium metal vapor followed by deflection in electric or magnetic fields to separate ^{235}U from un-ionized ^{238}U. The properties of the lasers and separating equipment required for this type of process are sketched with references to the limited information on systems for uranium metal vapor isotope separation in the unclassified literature.

Then a somewhat longer description is given of molecular methods in which a compound of ^{235}U, usually UF_6, is made to dissociate or react selectively by laser light in the presence of unreacting ^{238}U. Such molecular processes are being developed by the authors' Los Alamos Scientific Laboratory. To simplify the complex absorption spectrum of UF_6 sufficiently to obtain selective absorption of light by $^{235}UF_6$ in the presence of $^{238}UF_6$, it has been found desirable to supercool UF_6 vapor, by expanding a mixture of UF_6 and a noncondensing carrier gas through a supersonic nozzle. Irradiation of the supercooled gas by an infrared laser tuned to a frequency that excites $^{235}UF_6$ vibrationally but not $^{238}UF_6$, followed by irradiation with photons of sufficient energy to dissociate only the excited $^{235}UF_6$, converts gaseous $^{235}UF_6$ to a solid lower fluoride, which can be separated from undissociated gaseous $^{238}UF_6$ by physical means. This chapter is a good, brief, balanced description of these laser methods, within the restrictions set by security classification.

The final chapter, "Plasma Separating Effects," by F. Boeschoten and N. Nathrath, is primarily a brief account of the German authors' theoretical and experimental studies of isotope separation in rotating arcs. Brief mention is made other methods of isotope separation in ionized gases, including the ion cyclotron resonance process being studied in the U.S.

Manson Benedict

Massachusetts Institute of Technology
Department of Nuclear Engineering
Cambridge, Massachusetts 02139

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About the Reviewer: Manson Benedict is professor emeritus of nuclear engineering at the Massachusetts Institute of Technology (MIT). In the context of this review, however, he is best known for his outstanding contributions to the successful development of the gaseous diffusion process in the country during the World War II days. Dr. Benedict received his academic training at Cornell University and MIT. He has served industry in a number of research positions and the U.S. Atomic Energy Commission as chairman of its General Advisory Committee. He is a member of the National Academy of Engineering.