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(Editor's Note: Leo F. Epstein is with General Electric's Vallecitos Atomic Laboratory in Pleasanton, California. He has been engaged in nuclear activities for the past fifteen years, ten of them at KAPL, the last five in California, almost all of this time on some aspect of UO_2-fueled reactors.)

The Metallurgy of Hafnium. Edited by DONALD E. THOMAS AND EARL T. HAYES. For sale by Supt. of Documents, U. S. Government Printing Office, Washington 25, D. C., 1960 paperback, xii + 384 pp., $1.50.

As "The Metallurgy of Zr" neared completion (1955), the reviewer wrote to his co-editor, Ben Lustman, suggesting the publication of a companion volume on Hf. Ironically, some seven years later he finds himself in the critic's chair appraising the product of two of his valued friends and coworkers, Drs. Don Thomas and Earl Hayes, of long service with Westinghouse and the Bureau of Mines, respectively.

The editors have worked in the field of the so-called reactive metals since the late 40's and have played key roles notably in the early development of Zr and Hf. The reviewer has had the privilege of working closely with both, particularly during his Naval Reactors Branch sojourn (1950–55). The reader will appreciate the fact that these circumstances have made this review a special challenge.

In general the volume is very well written and adequately provided with tables and figures, table of contents, name and subject indices, etc. Some of the photographs are hazy but this is not a serious disadvantage. Unfortunately, the text contains many errors, most of which again are not serious; these will be taken up with the editors privately. In keeping with the tradition of this series the volume pays lavish tribute to its sponsor.

The volume can stand independent of the Zr field—almost! Herein lies one of the differences of philosophy between the editors and the reviewer. Although the text purports to avoid duplication, the paralleling with Zr is extensive. Many sections lean heavily on the book's progenitor "The Metallurgy of Zirconium."

Hafnium has been described, and not entirely facetiously, as "like zirconium—only more so!" Since the similarity between the two metals is great, the reviewer would have preferred to use Zr technology as a foundation and emphasized the differences in the Hf volume. The reviewer notes in this volume a persistence concerning the alleged difficulty of separating Zr–Hf. Let's be realistic—certainly the problem is less severe than that of separating isotopes—or columbium from niobium! Also, of special interest are the disruptions to the "natural" sequence of Ti–Zr–Hf as in the case of stress–strain (page 233), corrosion (page 282), reactivity (page 329). To this we might add the tetrachloride vapor pressures.

Chapter 1 should be limited to actual applications. The largest of these is nuclear, of course, and judging by recent articles by John Theilacker, Kermit Anderson, and others, the treatment here is hardly adequate. Regarding the nonnuclear applications, reference to Schwarzkopf and Kieffer's "Refractory Hard Metals" would show how little we know about a potentially valuable group of compounds. Based on Misch's electrolytic studies, the reviewer feels that Hf or its alloys might some day compete with Ta in the capacitor field.

Chapter 2, aided by process declassification, updates the Zr–Hf separations. The extraction methods are threatened by the Newnham disproportionation method (page 67), which was still under development last year at U. S. Industrial Chemicals Co. (*Chem. Eng. News*, **39**, 71 (1961)). Another challenger, now dormant, may be Bromberg's (duPont) distillation method (page 65). When will someone test A. F. Reid's fractional sublimation method on Zr–Hf separation? It is interesting to note that early discussions with Plucknett have been followed with patents (page 65).

Chapters 3 and 4 cover reduction and refining, respectively. A basic difference between Zr and Hf shows up dramatically here in the inability to use Hf sponge without refining. However, as was pointed out by the reviewer years ago, some cost savings can be effected by blending good sponge with X-bar made from poor sponge. One recalls Frank Block's (BuMines) study of pressure liquefaction which gave interesting results in $ZrCl_4$ purification and which might be tried for Hf. One's curiosity is aroused as to what the effect of the Petersen-Bromley film boiling method might be on HfI_4 dissolved in inert carrier salts. What if we replaced deBoer's filament with a levitated molten globule of Hf? The deBoer method is challenged by the electrolytic processes developed by Baker (BuMines) and Steinberg *et al.* (Horizons, Inc.). Also of interest here is Goldenberg's (NRL) Ti patent. Success in electrorefining will reflect in emphasis on electrowinning. And if the latter should succeed for Hf, can Zr be far behind?

Chapter 5 covers melting and fabrication; the electron beam melting section of Chapter 4 probably should have been included here. Chapter 6 covers what little is known about the alloys. Chapter 8 plods tediously through the analytical chemistry. Here, I start to miss Warren Blumenthal's "The Chemical Behavior of Zirconium."

Properties are scattered, with Chapter 1 covering nuclear, Chapter 7 physical, Chapter 9 thermodynamics. A better grouping or coordination would be desirable.

One of the most intriguing facets of Hf over the years has been the subtle interplay of supply–demand and yields in relation to supposed costs. A chapter on this area would have been most appropriate. Extending the prices quoted on page 8 the reviewer can add one serious industrial offer to produce X-bar at $1000/lb in exchange for residues at $1/lb (1950). The offer was, of course, rejected. However, material cost is but one factor; Hf rods must be compared with alternate rods on an over-all cradle-to-grave basis. Uses for spent Hf rods are not covered in the text.

The section on history which starts in the foreword and continues in Chapter 1 warrants a separate chapter. It is interesting that the recent history of Hf spanning hardly a decade can become so vague so soon. But between the lines of any tome lies many another story. The reviewer recalls flashes from the Hf panorama: The rows of drums of "useless" hafnium hydroxide stored at the Oak Ridge Y-12 plant. Alvin Radkowsky's initial skepticism over his re-

quest for a serious study of Hf rods, soon displaced by enthusiasm. Sherman Naymark's cooperation on the burnout test. John A. Kyger's firm backing of the program over strong administrative opposition. Zalman Shapiro's desperate early attempts to grow crystal bars from low-grade Hf biscuits, the only available feed material. William A. Johnson's clever cooperation at Bettis which put one rod into the Mark I Nautilus Prototype core as the proverbial "foot in the door" (first, one—then six). No doubt without the cooperation of these and other individuals the Hf program would have developed regardless. However, it would not have developed in time to avert the crisis deliberately masked by the statement on page 26. During final cleanup at Bettis an alert technician noticed that the rods did not ring right on tapping. One rod was then sectioned. This revealed extensive bond failure, rather than "blistering." And the Hf "scramble" was on!

Despite the differences of opinion noted above, the reviewer acknowledges the fact that this volume admirably rounds out the monographs on the Group IV Transition Metals and provides a sorely-needed focal point for further research on this little-known "orphan" element. Drs. Thomas and Hayes are to be commended for their contribution and admired for their stamina and, perhaps, forgiveness!

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(About the Reviewer: Mr. Kerze is currently with the High Temperature Reactors Branch of the U. S. Atomic Energy Commission's Division of Reactor Development. His experience in reactor materials is extensive. After working with Prof. H. C. Urey on H_2-D_2 catalytic exchange and UF_6 purification at Columbia University in 1940 to 1942, he taught Chemical Engineering at New York University for 4 years. Following this, he spent 4 years at Oak Ridge National Laboratory in the development of MTR fuel elements, as well as the beryllium reflector and the control and shim rods for that reactor. From 1950 to 1955 he was on Admiral Rickover's staff where he was concerned principally with the development of zirconium and hafnium. He was principally responsible for the development of the hafnium control rods for naval reactors. From 1955 to 1958 he was in charge of spent fuel reprocessing programs.)