Silver–Indium–Cadmium, a Control Rod Material for Pressurized Water Reactors

The following comments on recent work by Anderson *et al.* (*1*) regarding the use of silver–indium–cadmium as a control rod material for water moderated power reactors are important to anyone considering this material.

Ag–In–Cd was selected as a control rod absorber material for the Yankee and BR-3 pressurized water reactors after careful studies were made of its physical, mechanical, and nuclear properties. At Westinghouse Atomic Power Department, a development program was conducted on Ag–In–Cd which resulted in providing a corrosion resistant diffusion bonded nickel plating. The heat treatment required to obtain the protective diffusion bond also improved the creep strength of the material.

By plating the Ag–In–Cd alloy with 0.005 in. of nickel and heat-treating for four hours at 600°C, a diffusion bond forms that protects the base material from gross corrosive and galvanic attack in all pressurized water environments tested. Tests show that a nickel plate thickness of 0.0002 in. is resistant to galvanic corrosion; however, a nominal 0.0005 in. plating thickness is recommended due to variations at edges and corners during the plating process. The heat-treated nickel plate retains its integrity under indentation and normal surface abuse. The base alloy deforms under the nickel plate while the plating retains its protective features. Corrosion testing of drill hole defected specimens has revealed that the nickel plate does not undercut.

The 600°C diffusion heat-treatment given to the nickel plated Ag–In–Cd produces a grain size in the order of ASTM 0 to 2 which improves the creep strength of the material. At 550°F, with a load equal to a stress of 1000 psi, no appreciable elongation was observed in 1200 hr. The 0.2% offset yield strength is between 6300 psi and 9500 psi at 550°F, depending upon the strain rate. The yield strength of the material is more than adequate for the Yankee reactor since the maximum tensile stress obtained during scram will be in the order of 4860 psi.

Consideration of neutron absorption indicates that Ag–In–Cd control rods have more than sufficient endurance for power reactor applications. Both energy density (power density × core life) and control rod surface effectiveness (control rod surface to core volume ratio required to achieve a given reactivity reduction) must be considered in evaluating control rod endurance.

The Yankee reactor requires a control rod surface of 0.042 dm^2 per liter of core to achieve a reactivity reduction of 1%. This value does not exhibit a large variation with reactivity tied up in control rod absorption, as is illustrated by Fig. 1. This figure is based on data obtained during the hot, zero power critical experiments performed on Yankee Core I (*2*). Since the average design power density in Yankee Core I is 60 kw per liter, the core has a control rod surface requirement of 0.7 dm^2 per thermal Mw per per cent reactivity reduction. When more surface per unit volume is required, surface depletion effects are less per unit of energy density in the fuel, and control rod endurance is increased. Most low enrichment light water moderated reactors require a control rod surface to core volume ratio comparable to that for Yankee to achieve effective control.

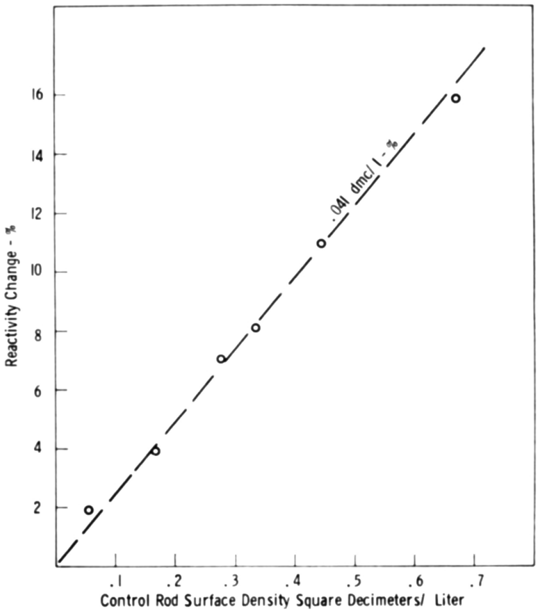

FIG. 1. Yankee Core I control rod worth vs. control rod surface. $T_{\mathrm{av.}} = 514°\mathrm{F}$.

Yankee uses programmed rod control in which only one group of control rods is removed from the core at a time. This method of control is common in large power reactors. A maximum of four control rods are in a position such that the depletion is greatest at the lower tip. In a rod programmed reactor, a greater fraction of the control rod residence time in core is taken up with the rod in a fully inserted position, the peak neutron flux moving from the lower third to the upper third of the core. Yankee also makes use of control rod interchange techniques (interchange of symmetrical control rod groups) in which no group of rods is in the core for the full core life. Although this is carried out to obtain more uniform fuel depletion, neutron absorption in control rods is also "averaged out." Consideration of these factors has yielded a conservative estimate for the maximum-to-average control rod surface absorption of 2.0 for the Yankee control rods.

Control rod surface absorption as a function of reactor energy density has been determined for the Yankee reactor for uniformly distributed control rods using few group diffusion theory calculations. These calculations yielded a value of 1.0×10^{-8} gm atom/sq dm for each kw-hr/liter of energy density. Since control rod worth is roughly proportional to control rod surface (Fig. 1), the value is not significantly dependent upon the magnitude of excess reactivity controlled.

The design life of the Yankee Core I is 10,000 hr, so that the average control-rod neutron-absorption density is roughly 0.06 gm atom of neutrons per square decimeter for the Core I lifetime. Multiplication of this factor by the maximum-to-average ratio of neutron absorption density, yields a maximum value for Core I of 0.12 gm atom of neutrons per square decimeter. Spatial control rod depletion calculations (*3*) indicate that this absorption density will reduce the control rod worth by roughly 2%. Since the Yankee total control rod worth is 16%, this corresponds to a maximum reactivity change of 0.3%. From the physics standpoint, the Yankee control rods will have sufficient absorption to be used in the second and possibly subsequent cores.

REFERENCES

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2. J. M. Gallagher *et al.*, The startup experiment program for the Yankee reactor. YAEC-184 (1961).
3. H. E. Walchli, Semi Annual Progress Report for the Period January 1, 1960 to June 30, 1960. Yankee Atomic Electric Company, YAEC-186 (1960).

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Book Review

Carbon-14 Compounds. By John R. Catch. Butterworth, Washington, D. C., 1961. 128 pp., $5.50.

The author is manager of the Organic Department at The Radiochemical Centre, Amersham, England. He has had many years of experience with carbon-14 compounds, especially with their synthesis.

The expressed purpose of this small book is to guide the reader to the literature and use of carbon-14. Catch begins by introducing the reader to the general literature on carbon-14 and then, in the following seven chapters, considers the production of carbon-14, chemical synthesis, biosynthesis, peculiar features of carbon-14 compounds, analytical application, measurement of carbon-14, and precautions for its safe handling. The chapter entitled "Peculiar Features of Organic Compounds" includes such varied subjects as isomerism, double labeling, isotopic asymmetry, isotope effects, radiation decomposition, and the nomenclature of carbon-14 compounds. The book contains a four-page appendix, which is a review of the publications that appeared during the preparation of the manuscript. No single subject is treated exhaustively, but most subjects are well documented; nearly 700 references are given. The extensive bibliographies are useful because the most recent comprehensive textbook on the subject of carbon isotopes appeared twelve years ago.

Catch writes in an easy, conversational style, and the reader will proceed without difficulty until he is plunged into the 58-word sentence in the middle of page 63.

The literature citations contain several errors. The confusing references on pages 65 and 66 to the review by Burr are collectively one example. The index comprises five pages, yet it is very cursory. For example, there is a good discussion of cyanide–C^{14} synthesis on pages 26–28, but reference to this discussion is not included in the index. As a result of several such omissions, the reader is forced to check the text as well as the index. This is not a formidable task in a book of this size.

All of the illustrations are located in the chapter entitled "Chemical Synthesis." A number of these could be omitted without detracting from the value of the book. The detailed discussion of nomenclature seems excessive compared with the brevity of treatment of other topics. The chapter, "Biological Methods of Labeling," reflects the growing interest, in both England and the United States, in biosynthesis with carbon-14. This chapter is interesting and informative but possibly will not be as useful as the chapters, "Peculiar Features," "Measurement," and "Precautions." The last chapter will be particularly valuable to anyone who considers carbon-14 to be an exceedingly hazardous material.

In brief, *Carbon-14 Compounds* is not a textbook. Instead, it is a guide that contains much good information and advice for organic chemists and biochemists who are beginning to use carbon-14. It will be equally useful to the expert for the references it contains.

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(*About the Reviewer: Dr. Vernon F. Raaen is currently a member of the Organic Chemistry Group at the Oak Ridge National Laboratory. He received his M.S. degree in organic chemistry at the University of Minnesota in 1950 and came to Oak Ridge in that year. He received his Ph.D. degree at the University of Tennessee in 1958. His work at the Laboratory has been research in organic chemistry with carbon-14 and the isotopes of hydrogen. He is currently coauthoring (with H. P. Raaen and G. A. Ropp) a book on the use of carbon-14 in organic chemistry.*)