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Symposium on Zirconium Costs

Sponsored by the Columbia National Corporation
February 13, 1958

Background Information

Columbia National Corporation was formed to provide zirconium to the Atomic Energy Commission and industry, and has recently completed the construction of a plant near Pensacola, Florida, with a potential annual production capacity of about one and one-half million pounds of hafnium-free reactor-grade zirconium sponge. The Corporation is jointly owned by Columbia Southern Chemicals Corporation, which produces inorganic chemicals, and National Research Corporation, which specializes in extractive and physical metallurgy. Since the production capacity of Columbia National's plant, as well as that of other zirconium plants in the United States, exceeds present AEC requirements, studies were initiated at Massachusetts Institute of Technology to explore the economics of using zirconium for cladding and structures in industrial power reactors as a basis for establishing the potential industrial demand. The symposium was set up to review the results of the MIT studies and discuss problems related to the economics of zirconium in power reactors with representatives from the AEC and industry. At the conclusion of the symposium, the following three reports, which have been placed in the X-10 Library, were distributed covering the MIT work:

1. "Break-Even Price of Zircaloy-2 Substituted for Stainless Steel in Nuclear Reactors: Sodium Graphite Reactor Designed by Atomics International for the Consumers Public Power District of Nebraska," George Jansen and Manson Benedict, October 3, 1957.
2. "The Economics of Using Zircaloy-2 as Cladding for Slightly Enriched Uranium fuel," MIT Thesis, Jack Jedruch, October 1957.
3. "Summary Report: Economic Comparison of Zircaloy and Stainless Steel in Nuclear Power Reactors," Manson Benedict, February 1958.

Break-Even Prices for Zirconium

The results of Dr. Manson Benedict's work are summarized as follows:

Use of zirconium (as Zircaloy) instead of less expensive stainless steel as structural material, fuel cladding, or fuel diluent in nuclear reactors makes savings possible through the use of uranium of lower enrichment and/or through reduction in the critical mass of uranium. The study compares the relative economics of using Zircaloy versus stainless steel in five power-producing thermal reactors, chosen so as to span the entire range of fuel enrichment from natural to highly-enriched uranium. Break-even prices of Zircaloy were computed for each reactor, i.e., the price

at which, with an annual return on capital investment of 15%, the lower cost of uranium inventory is just balanced by the difference in cost between Zircaloy and stainless steel. The reactors studied are:

	%	Break-Even Zircaloy Price, per lb.	
		<u>Fuel Cladding</u>	<u>Permanent Parts</u>
Natural Uranium, Heavy Water Reactor (Atomic Energy of Canada, Limited)	0.71	\$104	\$842
Sodium-Graphite Reactor (Atomics International)	1.8	57	592
Yankee Atomic Electric Reactor (Westinghouse)	2.6	51	-
Merchant Ship Reactor (Babcock and Wilcox)	3.64	44	141
Experimental Boiling Water Reactor (General Electric)	93	10	-

These studies indicate that Zircaloy should be used for permanent parts of commercial power-producing reactors fueled with uranium enriched up to at least 4% U-235. Zircaloy should be used to clad fuel elements of natural uranium. At prices of from \$40 to \$60 per pound for mill products it is definitely competitive with stainless steel for fuel cladding in slightly enriched reactors in which zirconium can be substituted for stainless steel on approximately a volume-for-volume basis. This is the basis for the above break-even prices.

The break-even price is roughly inversely proportional to the volume of Zircaloy substituted for one volume of stainless steel.

The break-even price of Zircaloy decreases as the U-235 enrichment of the fuel increases, because neutron economy is less important with more highly-enriched fuels. Should the AEC's rental charge against the value of the entire inventory of uranium, now only 4% per year, be raised to a level more representative of commercial interest rates prevailing both here and abroad, the break-even price of zirconium would be increased sharply. This will also be the result if the price of enriched uranium is raised.

The break-even price of Zircaloy used for permanent reactor parts increases slightly with increasing load factor. For cladding it increases with decreasing load factor; this indicates that Zircaloy should be seriously considered for cladding fuel elements, as well as permanent parts, in reactors which are not likely to be operated at load factors of 80% or more.

For a reactor operating at a given power level, the break-even price of Zircaloy increases as it becomes possible to increase the life-time of

the fuel in the reactor, i.e., as the fraction of fuel which is burned is increased, a higher price can be justified for the Zircaloy. The break-even price of Zircaloy also is higher with longer fuel life-time for a given burn-up fraction, since the Zircaloy need not then be replaced so frequently.

A significant measure of the economic incentive to use Zircaloy in preference to stainless steel is the annual return on the incremental investment made when substituting Zircaloy for stainless steel. At the break-even price, the return is 15%. As the prices of Zircaloy mill products are reduced below the break-even price, the return on the incremental investment rises sharply.

Fuel Costs in the Yankee Atomic Electric Plant with Zirconium and Stainless Steel Cladding

An estimate of fuel costs in the Yankee plant with stainless steel clad and zirconium clad fuel elements, respectively, was presented by Mr. Jedruch of Westinghouse Atomic Power Division. The results are summarized below which indicate a slight saving for 30 mil Zr compared to 30 mil stainless steel, but a slight loss compared to 15 mil stainless steel clad.

Fuel Costs, mills/kwh

	15 mil <u>Stainless Steel</u>	30 mil <u>Stainless Steel</u>	30 mil <u>Zirconium</u>
Cladding Material Costs ⁽¹⁾	0.21	0.22	0.75
Labor	0.24	0.24	0.34
Equipment Depreciation	0.04	0.04	0.07
Chemical Processing ⁽²⁾	0.72	0.75	0.61
Inventory Plus Burn-up, Less Pu Credit ⁽³⁾	<u>1.90</u>	<u>2.02</u>	<u>1.41</u>
TOTAL	3.11	3.27	3.18

(1) Zr at \$44/lb., S.S. at \$12/lb.

(2) Zr scrap credit based on 8% of metal at \$5/lb.-

(3) Pu credit at \$12/gram, inventory at 4% annual charge.

The Use of Zirconium and Stainless Steel in the Sodium Graphite Reactor

It was pointed out by a representative of Atomics International that with a zirconium cladding thickness twice that of a stainless clad, the break-even price of Zircaloy-2 tubing is \$30/lb. Technical considerations, however, rather than economic considerations have led to a choice of stainless clad fuel elements and stainless graphite cans for the Consumer's Public Power District Sodium Graphite Reactor. First of all, the problem of grain growth of Zr limits operating temperatures to 900° F, compared to 1000° F for stainless steel. Second, the possibility of oxygen pickup and subsequent embrittlement of the zirconium requires greater purification of the sodium in the case of Zr clad fuel. By redesigning the lattice

arrangement so that fuel elements are located at the corners of the hexagonal graphite moderator piece, rather than at the center, neutron absorption by the stainless steel moderator can has been reduced to the point where fuel enrichment (2.5%) is the same as with zirconium cans. The new design is outlined in NAA Atomics International Reports AI-1926, AI-1867, or AI-1869.

Zirconium Production Capacity

The potential production capacity of the major United States suppliers is given as follows for zirconium sponges:

<u>Company</u>	<u>Millions of lbs. per Year</u>
Columbia National	1.5
Carborundum	1.5
Mallory	2.0
Wah Chang	<u>1.0</u>
TOTAL	6.0

The AEC has contracted to purchase 2.6 million pounds per year, leaving an excess capacity of 3.4 million pounds for industry.

Zirconium Prices

The present price of zirconium sponge is \$7.50 per lb. based on an average plant production rate of 600,000 lbs./year. The estimated price of Zr sponge for a production rate of 1.5 million lbs. per year is \$4.00/lb.

A reduction in price of Zr sponge will also lower the price of tubing. At \$7.50/lb., seamless tubing costs \$55/lb. and welded tubing \$35/lb. at present. At \$4.00/lb. for sponge, tubing prices will drop to \$48/lb. and \$29/lb., respectively.

Factors Leading to Lower Zirconium Tubing Costs

In addition to projected lower tubing costs due to higher sponge production rates, lower costs of converting sponge to tubing by improving yields and scrap recovery procedures are also possible. In the titanium industry, cost of Ti sheet is \$10/lb. compared to Ti sponge at \$2.50/lb. It is hoped that a similar ratio of costs of sheet and tubing to sponge can be achieved for zirconium, which would reduce costs of tubing to approximately \$16/lb. A cost of \$30/lb. is predicted as achievable in the near future.

At the present time the cost of inspecting tubing is high. Approximate costs are:

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<u>Test</u>	<u>\$/ft. of Tubing</u>
Autoclave and Chemical Analysis	0.10-0.15
Ultrasonic Inspection	low
Helium Leak	0.20
X-Ray Analysis	1.50

It is seen that X-ray tests are major cost item. Elimination of these, if possible, will result in significant savings.

Zirconium Alloy Development

It was pointed out in the discussion that zirconium-aluminum alloys containing 8-20 wt. % Al show promise for obtaining high yield strengths at temperatures up to 1200° F.

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