82
10/11
OCT 11 1965

MASTER

BNWL-131 B

AEC
RESEARCH
and
DEVELOPMENT
REPORT

FABRICATION COSTS FOR PLUTONIUM FUEL ELEMENTS
PART B:
VARIABLE COSTS OF FABRICATING UO_2 - Pu_2 FUEL RODS
FOR THE EXPERIMENTAL BOILING WATER REACTOR

EBWR

C. H. BLOOMSTER

SEPTEMBER, 1965

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

RICHLAND, WASHINGTON

PACIFIC NORTHWEST LABORATORY operated by BATTELLE MEMORIAL INSTITUTE

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or limit the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

PRINTED BY/ FOR THE U. S. ATOMIC ENERGY COMMISSION

BNWL-131 B
UC-25, Metals, Ceramics,
and Materials

FIRST
UNRESTRICTED

TID-4500

SEP 29 1965
DISTRIBUTION
MADE

45 TH
EDITION

FABRICATION COSTS FOR PLUTONIUM FUEL ELEMENTS
PART B: VARIABLE COSTS OF FABRICATING $\text{UO}_2\text{-PuO}_2$ FUEL RODS
FOR THE EXPERIMENTAL BOILING WATER REACTOR

By
C. H. Bloomster

Ceramics Research and Development Section
Reactor and Materials Technology Department

September, 1965

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in USA. Price \$2.00. Available from the Clearinghouse for Federal
Scientific and Technical Information, National Bureau of Standards
U. S. Department of Commerce, Springfield, Virginia

FABRICATION COSTS FOR PLUTONIUM FUEL ELEMENTSPART B: VARIABLE COSTS OF FABRICATING $\text{UO}_2\text{-PuO}_2$ FUEL RODS
FOR THE EXPERIMENTAL BOILING WATER REACTORINTRODUCTION

This report describes the variable costs of fabricating 200 fuel rods for the Experimental Boiling Water Reactor (EBWR). One of the largest plutonium fuel development programs ever undertaken, the fabrication of EBWR experimental plutonium fuel was directly or indirectly responsible for several advancements and developments in plutonium fuel technology, particularly in the pneumatic impaction and vibrational compaction of mixed oxides and in nondestructive testing. Because the 200 fuel rods used to obtain the cost data for this report were the last of more than 2,200 to be fabricated, the costs represent an advanced stage of process development. Therefore, the costs are more typical of present than of past costs, and do not reflect the actual cost of the entire fabrication.

Part of a series on the costs of fabricating several types of plutonium-enriched fuels, this report is the second and includes all the variable shop costs incurred by the fabrication group. Cost figures which were left out of this report include those relative to research and development and several variables associated with nuclear materials such as conversion costs, use charges and losses.

Each of the first four reports in this series deal with a specific fuel design, and the costs therein are necessarily specific to the particular fabrication processes required by the fuel design. The costs, therefore, may vary widely and may not be applied, with indiscretion, to other plutonium fuel

fabrication processes. A summary report, which will follow these initial reports, will condense the data and present the costs in more general terms which may be applicable to analyzing various fuel fabrication schemes.

In addition to permitting later analyses, the purpose of the first four reports is to document actual experience in sufficient detail to identify important cost components, to assess the influence of yield and some processing variables on cost, and to improve internal planning, scheduling, and estimating. In the terms of scientific methodology, the first four reports represent data accumulation, which will be followed by classification and analyses having broader implications and useage.

In an effort to update and expand upon previous cost programs, these reports will cover fuel element fabrication costs on a laboratory scale ranging from hundreds to thousands of individual pieces. The first report dealt with the fabrication costs of plutonium-enriched fuel elements for the Plutonium Recycle Critical Facility (PRCF).

SUMMARY

The variable cost (Table I) of fabricating plutonium-enriched fuel rods for the EBWR came to \$198 per kg of fuel (as oxide). This represents a unit cost of \$164 per fuel rod. The costs were based on the fabrication of 200 fuel rods by a well developed, pneumatic impaction, vibrational compaction process. With a core length of 1.23 m, each fuel rod contained 829 grams of depleted UO_2 -1.5 wt% PuO_2 fuel.

The shop labor requirements for each rod were 5.53 man-hours direct labor and 1.61 man-hours indirect labor. The costs included the cost of replacing one end cap in each fuel

rod. Techniques were later developed to eliminate the need for end cap replacement. Elimination of this step would reduce the unit costs by 10% and the direct labor requirement by 1.0 man-hours. The direct material cost was \$48 per fuel rod. The variable costs included direct materials, some processing costs for nuclear materials, shop labor, maintenance, direct overhead, and consumable supplies, but did not include the cost of nuclear materials themselves, use charges, administrative overhead, research, development, or engineering costs.

DISCUSSION

The plutonium core loading in the EBWR at Argonne, Illinois, is part of the Plutonium Recycle Demonstration Program. The purpose of this program is to generate physics data on plutonium burnup in prototypes of commercial reactor power plants and to demonstrate the engineering feasibility of recycling plutonium in these reactors. For this program, more than 2,200 Zircaloy clad $\text{UO}_2\text{-PuO}_2$ fuel rods were fabricated to contain ~2000 kg of plutonium-bearing ceramic fuel material. Each rod was 1.4 m long and 1 cm in diameter and had 0.6 mm Zircaloy cladding. The fuel length was 1.23 m. A plenum was maintained above the fuel with the use of a spring-loaded zirconia pellet to hold the fuel in place. Each rod contained 829 grams of depleted $\text{UO}_2\text{-1.5 wt\% PuO}_2$ fuel. The mixed oxide fuel was made by the pneumatic impaction process, and the fuel rod was loaded by the vibrational compaction process.

The process costs were based on the fabrication of the last 200 fuel rods. Since more than 2,200 fuel rods were fabricated, the costs were based on a relatively high point of the learning curve, and the processes may be considered well developed. The costs in this report, therefore, represent the current "state of the art" and do not reflect the historic cost of the entire fabrication.

COST ACCUMULATION

Labor costs were obtained by means of daily job tickets which indicated the time worked on each process step, the output, and the time required for indirect work, such as housekeeping, record keeping, and accountability. Including wages and all fringe benefits, the average hourly wage rate for direct labor was \$4.85. The indirect laboratory expense, which was 175% of direct labor cost, covered a broad range of miscellaneous costs (e.g., general supplies, maintenance, and building expense) incurred by the fabrication group. These rates were in effect in March and April, 1965.

Direct materials, consumable supplies, and services were those costs actually incurred. The material costs included the zirconium, the stainless steel spring and zirconia pellet, the arc-fusion of UO_2 , and the purification and oxidation of plutonium metal. Consumable supplies consisted of cans, punches, and backup plugs for the pneumatic-impaction process, and some special plastic bags used in loading the cans and the fuel rods.

COST DATA

The cost and labor requirements for each process step are summarized on a single rod basis (Table II) and on a 100 kg basis (Table III). Accounting for over one-fourth of the processing and labor expenditures, the largest processing cost is the vibrational compaction step. The direct materials cost was also over one-fourth of the cost of the fuel rod.

The cost data are presented (Table V through XVI) for each process step. The yield, recycle rates, and losses were included, and the unit variable cost of each process step was calculated. In calculating the unit variable cost, the recycle material was valued at the material value of the process step to which it reenters. The samples, reject material, and material

unaccounted for (muf)* have no value in terms of variable processing cost. (In calculations including nuclear material costs, which are not considered for the present, the samples and reject material have value.) The value of the recycled fuel is deducted from the value of the fuel leaving the process, giving the value of the acceptable fuel leaving the process. This value is reduced to a unit value, and the unit cost of the process step is obtained by deducting the unit value of the fuel entering the process.

A flow diagram (Figure 1) and a brief description of the operations and costs involved in each process step** is given below.

Tubing Preparation (Table IV)

The tubing was identified, cut to length, counterbored, washed, and inspected. The direct material cost was \$35 for tubing. The cost of nondestructive testing was included in the tubing cost.

UO₂ Preparation (Table V)

Arc-fused depleted UO₂ was crushed to -65 mesh and packaged. A small quantity of UO₂ was converted to U₃O₈ to adjust the oxygen-to-uranium ratio for the pneumatic impaction step. Direct materials cost is for the arc-fusion of UO₂. Direct service charge is the analytical quality control of the UO₂.

* muf is an accountability term used for differences between book values and physical inventory values. It includes weighing and analytical variations, material lost to waste, and material later recovered from glove box filters.

**For more details and pictures of the process steps, see HW-79291, Specifications for Vibrationally Compacted, Mixed Oxide (UO₂-PuO₂) Fuel Elements for the PRTR (Mark 1-L). General Electric Company, Richland, October 1, 1963.

PuO₂ Preparation (Table VI)

The bulk of the plutonium oxide was prepared by oxidizing impure plutonium metal, and subsequently purifying the oxide. Since this process was laborious, an alternate process was developed in which the metal was purified by vacuum remelting before oxidation. The cost of this latter, more advanced process was used. The direct material cost was the cost of the purification and oxidation of plutonium. The processing cost was for verification of the PuO₂ weight and repackaging the PuO₂ in similar batches for the blending and loading step.

Loading Cans (Table VII)*Double-Canning (Table VIII)*Pneumatic Impaction (Table IX)*Opening (Table X)*Crushing and Sieving (Table XI)

The fuel was crushed and sieved into the proper size fractions, vacuum outgassed to remove volatile impurities, sampled for chemical quality control, and weighed into bottles in the proper amounts and size fractions for one fuel rod. Reject fuel consisted of glove box sweepings and other potentially or actually impure fuel which was returned for chemical recovery. To have a more significant sample size, the yield and recycle rates are based on the last ten lots (600 kg) of fuel processed. Direct service is the cost of chemical analyses to determine oxygen-to-metal ratios, plutonium contents and impurity levels.

*The pneumatic impaction process steps (Table VII through X) were common to all ceramic fuel processes. These steps and costs are described in more detail in BNWL-131 A.

Vibrational Compaction (Table XII)

Each bottle of fuel was loaded into the cladding with the use of high energy vibrational compaction. Previously, one end cap had been welded into the cladding. After loading, the end of the fuel rod was decontaminated. Consumable supplies are the costs of fittings and a plastic bag used to attach the fuel rod to the glove box during vibrational compaction, the end cap which is replaced, and filter plugs inserted in the end of the fuel rod after following decontamination.

Welding and End Cap Replacement (Table XIII)

The second end cap was welded in place. The first end cap was removed and replaced. Minute fatigue cracks developed in the weld zone of many fuel rods during vibrational compaction. Since the cracks seemed to propagate during thermal cycling tests, all first end caps were replaced. Both end zones were ultrasonically tested for defects. Later work indicates that conditions can be controlled to prevent cracks. Elimination of the end cap replacement step would reduce the unit cost by 10%. Direct materials are the cost of the end caps and the spring and pellet.

Finishing (Table XIV)

The fuel rods were etched, autoclaved, tested in a helium-leak detector, inspected, and packaged for shipping. Direct material cost is for a stainless steel stem, attached externally to one end cap, which is used for positioning the fuel rods in the EBWR fuel array.

Rework (Table XV)

The recycled material required a small amount of additional work before it reentered the process.

Indirect (Table XVI)

This category included record keeping, accountability, procurement of supplies, and other indirect work attributed directly to the fabrication job. Not being attributable directly to a particular job, indirect time devoted to general cleanup, meetings, breaks, etc., was also included. These latter indirect costs were prorated on a labor hours basis to each job in process during the period under study.

Material Requirements

The direct material requirements for each process step are shown in Table XVII. The plutonium losses (muf) were 0.7%, and the plutonium to be recovered from samples and reject fuel was 7.9%. The uranium losses (muf) were 1.3%, and the uranium to be recovered from samples and reject fuels was 9.2%. The zirconium losses were 9%. The combined recycle-reject rate of the mixed oxide fuel was 17.3% for the powder preparation processes and the fuel recycle rate was 9.0% for the rod fabrication process.

ACKNOWLEDGMENT

The author is indebted to the members of Plutonium Fuels Engineering for their assistance and cooperation in preparing this report. The author is grateful to R. E. Sharp for providing processing information and to Miss Shonnie Hays for clerical assistance.

TABLE IVARIABLE COSTS OF FABRICATING EBWR FUEL RODS

	<u>Cost Per Rod</u>	<u>Cost Per 100 kg</u>
Direct Materials		
Zirconium	\$38.00	\$4590
Uranium	3.59	434
Plutonium	5.60	676
Other	5.13	619
Direct Labor	34.70	4190
Supplies	7.40	893
Direct Services	4.65	560
Laboratory Expense	60.80	7330
Reject Expense	4.30	520
	<u>\$164.17</u>	<u>\$19,812</u>

TABLE II.VARIABLE COSTS PER ROD

	<u>Direct Materials</u>	<u>Processing</u>	
		<u>\$</u>	<u>Man-hours</u>
Tubing Preparation	\$35.00	1.68	0.137
UO ₂ Preparation	3.59	3.04	0.224
PuO ₂ Preparation	5.60	1.17	0.055
Loading Pneumatic Impaction		3.53	0.231
Double-Canning		1.09	0.032
Pneumatic Impaction		2.37	0.178
Opening		1.62	0.092
Crush and Sieve		13.32	0.690
Vibrational Compaction		32.90	1.904
Welding and End Cap Replacement	3.63	19.75	1.318
Finishing	4.50	8.81	0.583
Rework		1.21	0.091
Indirect		21.50	1.614
	<u>\$52.32</u>	<u>\$111.97</u>	<u>7.149</u>
		<u>52.32</u>	
		<u>\$164.29</u>	

TABLE IIIVARIABLE COSTS PER 100 kg

	<u>Direct Materials</u>	<u>Processing</u>	
		<u>\$</u>	<u>Man-Hours</u>
Zirconium Preparation	4220	203	16.5
UO ₂ Preparation	434	367	27.0
PuO ₂ Preparation	675	143	6.6
Loading Pneumatic. Impaction Cans		426	27.9
Double-Canning		132	3.9
Pneumatic Impaction		288	21.5
Opening		195	11.1
Crush and Sieve		1609	83.3
Vibrational Compaction		3969	230.0
Welding and End Cap Replacement	438	2375	159.0
Finishing	543	1066	70.4
Rework		146	11.0
Indirect		2597	195.0
	<hr/>	<hr/>	<hr/>
	\$6310	\$13,516	863.2
		<hr/>	
		6,310	
		<hr/>	
		\$19,826	

TABLE IVTUBING PREPARATION, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	Tubing, \$35.00 per tube	\$4220
Consumable Supplies	0	
Direct Labor	0.126 Man-Hours per tube	74
Laboratory Expense	175%	129
Direct Services	0	
Total Shop Cost		<u>\$4423</u>

OUTPUTS

	<u>Percent</u>	<u>Output Per 109.0 kg In</u>
Yield	100	109.0
Recycle		
Samples		
Reject		
muf		

VALUE ANALYSIS

Value of Direct Material Entering Process	\$4220
Process Variable Cost per 100 kg Fuel	\$ <u>203</u>
Total Value 100 kg Fuel Leaving Process	\$4423
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	109.0 kg
Total Value of 109.0 kg Fuel Leaving Process	
Value of Recycle: 0 kg @ \$0 per kg	
Total Value of 109.0 kg Acceptable Fuel	
Unit Value of 100 kg Fuel Entering Next Process	\$4423
Value of Material Entering This Process	<u>\$4220</u>
Process Variable Cost per 100 kg Acceptable Fuel	<u>\$ 203</u>

TABLE V

UO₂ PREPARATION, EBWR
(98.5% UO₂)

INPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	\$2.00 per pound UO ₂	\$434
Consumable Supplies	0	
Direct Labor	0.245 Man-Hours per kg out	119
Laboratory Expense	175%	207
Direct Services	Analytical \$0.25 per kg	25
Total Shop Cost		<u>\$785</u>

OUTPUTS

	<u>Percent</u>	<u>Output Per 110.5 kg In</u>
Yield	98	108.2
Recycle		
Samples	1/2	.6
Reject	1	1.1
muf	1/2	.6

VALUE ANALYSIS

Value of Material Entering Process	\$434
Process Variable Cost per 100 kg Fuel	<u>\$351</u>
Total Value 100 kg Fuel Leaving Process	\$785
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod 110.5 kg	
Total Value of 110.5 kg Fuel Leaving Process	\$867
Value of Recycle: 0 kg @ \$0 per kg	<u>\$ 0</u>
Total Value of 108.2 kg Acceptable Fuel	\$867
Unit Value of 100 kg Fuel Entering Next Process	\$801
Value of Material Entering This Process	<u>\$434</u>
Process Variable Cost per 100 kg Acceptable Fuel	<u><u>\$367</u></u>

TABLE VIPuO₂ PREPARATION, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	\$0.45 per gram PuO ₂	\$675.
Consumable Supplies	0	
Direct Labor	4.06 Man-Hours per kg PuO ₂	.29
Laboratory Expense	175%	52
Direct Services	Analytical \$40 per kg	60
Total Shop Cost		<u>\$816.</u>

OUTPUTS

	<u>Percent</u>	<u>Output Per 108.6 kg In</u>
Yield	99.7	108.2
Recycle	0	
Samples	0.2	.2+
Reject	0	
muf	0.1	.1+

VALUE ANALYSIS

Value of Material Entering Process	\$675
Process Variable Cost per 100 kg Fuel	<u>\$141</u>
Total Value 100 kg Fuel Leaving Process	\$816
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod 108.6 kg	
Total Value of 108.6 kg Fuel Leaving Process	\$886
Value of Recycle: 0 kg @ \$0 per kg	<u>\$ 0</u>
Total Value of 108.2 kg Acceptable Fuel	\$886
Unit Value of 100 kg Fuel Entering Next Process	\$818
Value of Material Entering This Process	<u>\$675</u>
Process Variable Cost per 100 kg Acceptable Fuel	<u>\$143</u>

TABLE VIILOADING CAPS FOR PNEUMATIC IMPACTION, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	0	
Consumable Supplies	\$6.10 per 6 kg	\$102
Direct Labor	1.452 Man-Hours per 6 kg	117
Laboratory Expense	175%	205
Direct Services	0	
Total Shop Cost		<u>\$424</u>

OUTPUTS

	<u>Percent</u>	<u>Output Per 117.3 kg In</u>
Yield	99.87	117.2
Recycle	0.1	.1
Samples	0	
Reject	0.078	
muf	0.004	

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$1619
Process Variable Cost per 100 kg Fuel	<u>\$ 424</u>
Total Value 100 kg Fuel Leaving Process	\$2043
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	117.3 kg
Total Value of 117.3 kg Fuel Leaving Process	\$2400
Value of Recycle: 0.1 kg @ \$16 per kg	<u>\$ 2</u>
Total Value of 117.2 kg Acceptable Fuel	\$2398
Unit Value of 100 kg Fuel Entering Next Process	\$2045
Value of 100 kg Fuel Entering This Process	<u>\$1619</u>
Process Variable Cost per 100 kg Acceptable Fuel	<u>\$ 426</u>

TABLE VIIIDOUBLE-CANNING, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	0	
Consummable Supplies	\$5.25 per 6 kg	\$ 88
Direct Labor	0.199 Man-Hours per 6 kg	16
Laboratory Expense	175%	28
Direct Services	0	
Total Shop Cost		\$132

OUTPUTS

	<u>Percent</u>	<u>Output Per kg In</u>
Yield	100	
Recycle		
Samples		
Reject		
muf		

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$2045
Process Variable Cost per 100 kg Fuel	\$ <u>132</u>
Total Value 100 kg Fuel Leaving Process	\$2177
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	
Total Value of 0 kg Fuel Leaving Process	
Value of Recycle: 0 kg @ \$0 per kg	
Total Value of 0 kg Acceptable Fuel	
Unit Value of 100 kg Fuel Entering Next Process	\$2177
Value of 100 kg Fuel Entering This Process	\$ <u>2045</u>
Process Variable Cost per 100 kg Acceptable Fuel	\$ <u><u>132</u></u>

TABLE IXPNEUMATIC IMPACTION, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	0	
Consumable Supplies	\$1.64 per 6 kg	\$ 27
Direct Labor	1.090 Man-Hours per 6 kg	88
Laboratory Expense	175%	154
Direct Services		
Total Shop Cost		<u>\$269</u>

OUTPUTS

	<u>Percent</u>	<u>Output Per 117.2 kg In</u>
Yield	97.39	114.2
Recycle	2.60	3.0
Samples	0	
Reject	0	
muf	0	

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$2177
Process Variable Cost per 100 kg Fuel	<u>\$ 269</u>
Total Value 100 kg Fuel Leaving Process	\$2446
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	117.2 kg
Total Value of 117.2 kg Fuel Leaving Process	\$2870
Value of Recycle: 3.0 kg @ \$16.19 per kg	<u>\$ 49</u>
Total Value of 114.2 kg Acceptable Fuel	\$2821
Unit Value of 100 kg Fuel Entering Next Process	\$2465
Value of 100 kg Fuel Entering This Process	<u>\$2177</u>
Process Variable Cost per 100 kg Acceptable Fuel	<u><u>\$ 288</u></u>

TABLE XOPEN PNEUMATIC IMPACTION CANS, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	0	
Consumable Supplies	0	
Direct Labor	0.588 Man-Hours per 6 kg	\$ 48
Laboratory Expense	175%	83
Direct Services	Density Samples	50
Total Shop Cost		<u>\$181</u>

OUTPUTS

	<u>Percent</u>	<u>Cost Per 114.2 kg In</u>
Yield	99.52	113.8
Recycle	0	
Samples	0.25	.2
Reject	0.23	.2
muf	0	

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$2465
Process Variable Cost per 100 kg Fuel	<u>\$ 181</u>
Total Value 100 kg Fuel Leaving Process	\$2646
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	114.2 kg
Total Value of 114.2 kg Fuel Leaving Process	\$3025
Value of Recycle: 0 kg @ \$0 per kg	<u>\$ 0</u>
Total Value of 113.8 kg Acceptable Fuel	\$3025
Unit Value of 100 kg Fuel Entering Next Process	\$2660
Value of 100 kg Fuel Entering This Process	<u>\$2465</u>
Process Variable Cost per 100 kg Acceptable Fuel	<u>\$ 195</u>

TABLE XICRUSHING AND SIEVING, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	0	
Consumable Supplies	0	
Direct Labor	0.733 Man-Hours per kg	\$ 356
Laboratory Expense	175%	622
Direct Services	Analytical \$140 per kg	194
Total Shop Cost		<u>\$1172</u>

OUTPUTS

	<u>Percent</u>	<u>Output per 113.8 kg In</u>
Yield	87.92	100.0
Recycle	4.92	5.6
Samples	2.39	2.8
Reject	4.23	4.8
muf	0.54	.6

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$2660
Process Variable Cost per 100 kg Fuel	<u>\$1172</u>
Total Value 100 kg Fuel Leaving Process	\$3832
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	113.8 kg
Total Value of 113.8 kg Fuel Leaving Process	\$4360
Value of Recycle: 5.6 kg @ \$16.19 per kg	<u>\$ 91</u>
Total Value of 100 kg Acceptable Fuel	\$4269
Unit Value of 100 kg Fuel Entering Next Process	\$4269
Value of 100 kg Fuel Entering This Process	<u>\$2660</u>
Process Variable Cost per 100 kg Acceptable Fuel	<u><u>\$1609</u></u>

TABLE XIIVIBRATIONAL COMPACTION THROUGH DECONTAMINATION, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	0	
Consumable Supplies	\$5.28 per Rod	\$ 637
Direct Labor	1.746 Man-Hours per Rod	1021
Laboratory Expense	175%	1788
Direct Services	0	
Total Shop Cost		\$3446

OUTPUTS

	<u>Percent</u>	<u>Output Per 109.0 kg In</u>
Yield	93.7	102.2
Recycle	6.3	6.8
Samples		
Reject		
muf		

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process (Fuel, \$4269; Zr, \$4423)	\$ 8692
Process Variable Cost per 100 kg Fuel	\$ <u>3446</u>
Total Value 100 kg Fuel Loading Process	\$12138
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	109.0 kg
Total Value of 109.0 kg Fuel Leaving Process	\$13230
Value of Recycle: 6.8 kg @ \$42.69 per kg	\$ <u>290</u>
Total Value of 102.2 kg Acceptable Fuel	\$12940
Unit Value of 100 kg Fuel Entering Next Process	\$12661
Value of 100 kg Fuel Entering This Process	\$ <u>8692</u>
Process Variable Cost per 100 kg Acceptable Fuel	\$ <u><u>3969</u></u>

TABLE XIIIWELDING AND END CAP REPLACEMENT, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	\$3.63 per Rod	\$ 438
Consumable Supplies	0	
Direct Labor	1.289 Man Hours per Rod	754
Laboratory Expense	175%	1319
Direct Services	Non-Destructive Testing	181
Total Shop Cost		<u>\$2692</u>

OUTPUTS

	<u>Percent</u>	<u>Output Per 102.2 kg In</u>
Yield	98.96	101.1
Recycle	1.04	1.1
Samples	0	
Reject	0	
muf	0	

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$12661
Process Variable Cost per 100 kg Fuel	<u>\$ 2692</u>
Total Value 100 kg Fuel Leaving Process	\$15353
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	102.2 kg
Total Value of 102.2 kg Fuel Leaving Process	\$15691
Value of Recycle: 1.1 kg @ \$42.69 per kg	<u>\$ 47</u>
Total Value of 101.1 kg Acceptable Fuel	\$15644
Unit Value of 100 kg Fuel Entering Next Process	\$15474
Value of 100 kg Fuel Entering This Process	<u>\$12661</u>
Process Variable Cost per 100 kg Acceptable Fuel	<u><u>\$ 2813</u></u>

TABLE XIVFINISHING - STARTING AFTER WELD OF 2ND END CAP, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	\$4.50	\$543
Consumable Supplies	0	
Direct Labor	0.576 Man-Hours per Rod	337
Laboratory Expense	175%	590
Direct Services		
Total Shop Cost		\$1470

OUTPUTS

	<u>Percent</u>	<u>Output Per 101.1 kg In</u>
Yield	98.95	100.0
Recycle	1.05	1.1
Samples		
Reject		
muf		

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$15474
Process Variable Cost per 100 kg Fuel	\$ 1470
Total Value 100 kg Fuel Leaving Process	\$16944
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	101.1 kg
Total Value of 101.1 kg Fuel Leaving Process	\$17130
Value of Recycle: 1.1 kg @ \$42.69 per kg	\$ 47
Total Value of 100 kg Acceptable Fuel	\$17083
Unit Value of 100 kg Fuel Entering Next Process	\$17083
Value of 100 kg Fuel Entering This Process	\$15474
Process Variable Cost per 100 kg Acceptable Fuel	\$ 1609

TABLE XV.REWORK, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	0	
Consumable Supplies	0	
Direct Labor	.091 Man-Hours per Rod	\$ 53
Laboratory Expense	175%	93
Direct Services	0	
Total Shop Cost		<u>\$146</u>

OUTPUTS

	<u>Percent</u>	<u>Output Per kg In</u>
Yield	100	
Recycle		
Samples		
Reject		
muf		

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$17083
Process Variable Cost per 100 kg Fuel	\$ <u>146</u>
Total Value 100 kg Fuel Leaving Process	\$17229
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	
Total Value of 0 kg Fuel Leaving Process	
Value of Recycle: 0 kg @ \$0 per kg	
Total Value of 0 kg Acceptable Fuel	
Unit Value of 100 kg Fuel Entering Next Process	\$17229
Value of 100 kg Fuel Entering This Process	
Process Variable Cost per 100 kg Acceptable Fuel	\$ <u><u>146</u></u>

TABLE XVIINDIRECT, EBWRINPUTS

<u>Variable Costs</u>	<u>Primary Units</u>	<u>Cost Per 100 kg In</u>
Direct Material	0	
Consumable Supplies	0	
Direct Labor	1.614 Man-Hours per Rod	\$ 945
Laboratory Expense	175%	1652
Direct Services	0	
Total Shop Cost		<u>\$2597</u>

OUTPUTS

	<u>Percent</u>	<u>Output Per kg In</u>
Yield	100	
Recycle		
Samples		
Reject		
muf		

VALUE ANALYSIS

Value of 100 kg Fuel Entering Process	\$17229
Process Variable Cost per 100 kg Fuel	<u>\$ 2597</u>
Total Value 100 kg Fuel Leaving Process	\$19826
Quantity of Fuel Processed per 100 kg Fuel in Finished Rod	
Total Value of 0 kg Fuel Leaving Process	
Value of Recycle: 0 kg @ \$0 per kg	
Total Value of 0 kg Acceptable Fuel	
Unit Value of 100 kg Fuel Entering Next Process	\$19826
Value of 100 kg Fuel Entering This Process	
Process Variable Cost per 100 kg Acceptable Fuel	<u>\$ 2597</u>

TABLE XVII

MATERIAL REQUIREMENTS PER PROCESS STEP, kg

<u>Process Step</u>	<u>Fuel</u>		<u>Zirconium</u>		<u>Uranium</u>		<u>Plutonium</u>	
	<u>In</u>	<u>Out</u>	<u>In</u>	<u>Out</u>	<u>In</u>	<u>Out</u>	<u>In</u>	<u>Out</u>
Tubing Preparation			1.090	1.090				
UO ₂ Preparation					1.105	1.082		
PuO ₂ Preparation							1.086	1.082
Load	1.173	1.173			1.082	1.082	1.082	1.082
Double-Can	1.172	1.172			1.082	1.082	1.082	1.082
Pneumatic Impaction	1.172	1.142			1.082	1.082	1.082	1.082
Open	1.142	1.138			1.082	1.078	1.082	1.078
Crush	1.138	1.000			1.078	1.000	1.078	1.000
Vibrational Compaction	1.090	1.022	1.090	1.022				
Finish	1.022	1.010	1.022	1.010				
Replace End Cap	1.010	1.000	1.010	1.000				
Rework	1.000	1.000	1.000	1.000				
Indirect	1.000	1.000	1.000	1.000				

ONSITE DISTRIBUTIONCopy NumberPacific Northwest Laboratory

1	F. W. Albaugh
2	H. J. Anderson
3	R. J. Anicetti
4	E. R. Astley
5	W. J. Bailey
6	R. E. Bardsley
7-16	C. H. Bloomster
17	D. W. Brite
18	C. A. Burgess
19	J. B. Burnham
20	D. R. Burroughs
21	S. H. Bush
22	J. J. Cadwell
23	G. W. Dalen
24	F. G. Dawson, Jr.
25-26	D. R. deHalas
27	R. F. Dickerson
28-29	K. Drumheller
30	E. A. Eschbach
31	S. L. Fawcett
32	J. C. Fox
33	M. D. Freshley
34	S. Goldsmith
35	R. L. Gulley
36	J. R. Hague
37-38	W. L. Hampson
39	H. Harty
40	J. J. Hauth
41	R. J. Hennig

ONSITE DISTRIBUTIONCopy Number

42	J. P. Keenan
43	L. C. Lemon
44	W. R. Lewis
45	R. J. Lobsinger
46	L. G. Merker
47-48	R. E. Olson
49	H. M. Parker
50	E. H. Peterson
51	W. D. Richmond
52-53	W. E. Roake
54	R. K. Robinson
55	R. E. Sharp
56	L. W. Lang
57	C. H. Shaw
58-59	R. E. Skavdahl
60	R. C. Smith
61	O. J. Wick
62	R. D. Widrig
63	H. R. Wisely
64	F. W. Woodfield
65-66	Technical Publications, 300 Area
67	Technical Publications, 700 Area
68-72	Technical Information Files

General Electric Company, Richland

73	T. W. Ambrose
74	R. L. Dickeman
75	T. W. Evans
76	O. H. Greagor
77	L. T. Hagie
78	H. H. Hopkins

ONSITE DISTRIBUTIONCopy Number

79	L. E. Kusler
80	R. Y. Lyon
81	E. A. Smith
82	J. T. Stringer
83	GETA File

Richland Operations Office

84	P. G. Holsted
85-86	R. K. Sharp
87	Technical Information Library

OFFSITE DISTRIBUTION (SPECIAL)No. of Copies

1	ALKEM 7501 Leopoldshafen Karlsruhe, Germany Attn: W. Stoll
6	Argonne National Laboratory Attn: C. H. Bean J. H. Handwerk J. H. Kettel R. Macherey J. F. Schumar J. E. Ayer
1	Associazione Euratom-CNEN Per I Reattori Veloci Via Mazzini 2 Bologna, Italy Attn: F. Pierantoni
6	Atomic Energy Commission, Washington Division of Reactor Development Attn: R. Grube J. M. Morrissey F. C. Shwenk J. M. Simmons W. R. Voigt M. J. Whitman
1	Atomic Energy Commission, Washington Division of Research Attn: W. F. Sheely

OFFSITE DISTRIBUTION (SPECIAL)No. of Copies

1	Atomic Energy Research Establishment Chemistry and Metallurgy Branch Fuels Development Branch Chalk River, Ontario, Canada Attn: J. A. L. Robertson
4	Atomic Energy Research Establishment United Kingdom Atomic Energy Authority Harwell, Didcot, Berks, England Attn: P. Murray (3) L. E. Russell
1	Atomics International Attn: B. R. Hayward
2	Atomic Power Development Associates 119 First Street Detroit 26, Michigan Attn: W. H. Jens A. A. Shoudy
4	Battelle Memorial Institute Attn: D. L. Keller S. W. Porembka (2) W. F. Heenan
1	Centre d'Etudes Nucleaires de Cadarache Poite Postale No. 1 Saint-Paul-Lez-Durance, France Attn: Dr. B. Devreyn
1	Combustion Engineering, Inc. Attn: J. C. Tobin
1	European Atomic Energy Community 51-53 Rue Belliard (Euratom) Brussels 4, Belgium Attn: Pierre Druys
1	General Electric Company, APD Special Purpose Nuclear Systems Operation P. O. Box 450 Palo Alto, California Attn: H. Miller
3	General Electric Company, Cincinnati Attn: E. A. Aitken W. Briskin J. McGurty

OFFSITE DISTRIBUTION (SPECIAL)No. of Copies

3	General Electric Company, Pleasanton Attn: L. P. Bupp E. A. Evans A. I. Kaznoff
5	General Electric Company, San Jose Attn: K. Cohen A. N. Holden T. J. Pashos B. Weidenbaum E. L. Zebroski
1	Kerr-McGee Indus. Inc. Oklahoma City, Oklahoma Attn: Harold Lambertus
1	Knolls Atomic Power Laboratory Attn: W. K. Barney
5	Los Alamos Scientific Laboratory Attn: R. Baker M. Bowman H. Hessing D. McMillan R. Spence
2	NASA Lewis Research Center Attn: A. F. Lietzke N. T. Saunders
1	Transuranium Institute (Euratom) Karlsstrasse 42-44 Karlsruhe, Germany Attn: H. M. Mattys
4	Union Carbide Corporation (ORNL) Attn: R. M. Carroll J. L. Scott W. C. Thurber T. F. Connally
1	United Aircraft Corporation Research Laboratory East Hartford, Connecticut Attn: G. H. McLafferty
1	University of Arizona (Nuclear Eng. Dept.) Tucson, Arizona Attn: Monte V. Davis

OFFSITE DISTRIBUTION (SPECIAL)No. of Copies

1	University of Michigan College of Engineering Ann Arbor, Michigan Attn: W. Kerr
3	U. S. Atomic Energy Commission Brussels, Belgium Attn: C. F. Schank
2	Westinghouse Bettis Atomic Power Laboratory Attn: J. Belle B. Lustman
3	Westinghouse Electric Corporation Attn: Robert Allio A. A. Bishop A. Boltax
1	Wright Air Development Center AF Materials Laboratory Wright-Patterson AFB, Dayton, Ohio Attn: S. W. Bradstreet