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OPERATING EXPERIENCE IN A SEMIREMOTE FACILITY FOR FABRICATION
OF FUEL RODS CONTAINING $(^{233}\text{U}, \text{Th})\text{O}_2^*$

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INTRODUCTION

At the Eleventh Conference on Hot Laboratories and Equipment at New York in 1963, a facility and the equipment to fabricate fuel rods containing (Th-3 wt % ^{233}U) O_2 was described and the operational experience with thorium-depleted uranium oxide was presented (1).

As a part of the Thorium-Uranium Fuel Cycle Program, the Metals and Ceramics Division of the Oak Ridge National Laboratory processed 1100 fuel rods containing over 878 kg of powdered oxide to be used at Brookhaven National Laboratory in a zero-power criticality experiment. The primary objective was the collection of engineering and economic data for future studies; the secondary objective was the efficient, production-type operation of the plant.

The facility is housed in a chemical processing cell, thus enabling the use of the cell as secondary containment as well as the use of the built-in air handling system. The rod fabrication portion of the facility occupies two levels of a three-level plant, the third level housing the oxide preparation plant.

The fuel rod is a 0.5-in.-OD Zircaloy-2 tube with 0.035-in. walls. Two lengths of rods were fabricated: 46- and 19-in. long. p. 2

The cone-shaped bottom end plug is used for positioning in the critical

lattice while the threaded top end plug accepts a fitting used as an aid in handling.

The preparation of the properly sized powder to fill these rods consists of comminution, classifying, weighing, and blending. The blended powder is next compacted into the rod, the top end closure weld made, the rod ultrasonically cleaned, the density variations within the rod determined by a gamma-ray densitometer, the welds leak checked, and the rod loaded into the carrier.

This paper contains a brief description of the facility and of the rod fabrication process, with emphasis on those areas which were altered since the previous paper. The operating experience covered is that using ^{233}U and will be developed to include the utilization of time and manpower, the material inventory, the radiation monitoring program, and the economics of the process.

FUEL ROD DESIGN

The configuration of the reference fuel rod to be fabricated in the facility for the BNL critical experiments is shown in Fig. 1. The BNL experiments require 900 of these rods and 200 rods identical in design except that they are 18 in. in length instead of 46 1/16 in.

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Design Features of the BNL Fuel Rod.

The nominal compaction density was not specified by BNL but was determined from the average density of the fuel rods fabricated. It was specified that the rods will have a fuel density of $\pm 2\%$ of this determined average density and the density within a fuel rod will be $\pm 2\%$ of the average for that fuel rod. Based on experience with depleted (U,Th) O_2 in the "cold" operation of the facility, an average density of 90% of theoretical was expected and was obtained using (Th-3 wt % ^{233}U) O_2 .

The cone-shaped Zircaloy-2 bottom fitting, which will be used to direct the rod in the critical lattice at BNL, is welded onto the tube in a gas tungsten-arc welding operation, which is done outside the facility. The annular groove in the bottom plug is used as a handling aid during fabrication. In the facility, the top plug, ceramic spacer, and spring are inserted into the fuel tube after compaction as a unit. The ceramic spacer and spring are used in the void area at the top of the fuel rod to prevent redistribution of the fuel during handling. The Zircaloy-2 top end plug, joined onto the fuel tube by a fusion edge weld in the facility, is threaded to accommodate the stainless steel hanger fixture. This hanger fitting will be used to facilitate handling of the fuel rod in the critical lattice.

PROCESS

The rod fabrication process (Fig. 2) starts with the delivery of the bulk sol-gel oxide to the powder preparation equipment. The material is first crushed in a jaw crusher and separated by a continuous screen classifier into three size fractions: +6, -6+16, and -16. Through recycling of the +6 fraction and judicious charging of the ball mill with the -6+16 and -16, sufficient amounts of coarse and fine powders consisting of 55% -6+16 and 45% unclassified fines are produced. The development of the process to produce the fine fraction will be considered in the "cold" operation section. The two fractions are then separately weighed out on an automatic batch weigher, blended in a "V" blender, and using a vibrating feeder, fed into the rods. The powder is densified using an air driven vibratory compactor during feeding followed by additional densification with a weighted rider rod resting on top of the fuel column. The end cap, spacer, and spring are then placed in the rod and the end closure weld made. Next, the rod is ultrasonically cleaned and gamma scanned to determine the density fluctuations along the long axis. The welds are then helium leak checked and the rod smeared and cleaned until the smear count is < 2000 dis/min. Finally, the rod is loaded into the carrier for shipment.

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Fuel Rod Fabrication Flowsheet

FACILITY

The rod fabrication facility occupies the lower two levels of a three-level facility shown in Fig. 3. The third level houses the sol-gel process. The facility was constructed in an unused chemical-processing cell to take advantage of the air-handling equipment and to use the existing cell walls for secondary containment. Located in one corner of the first level and extending to the top of the second level is the 4- X 7-ft powder preparation shaft. Adjacent to this shaft, on the first level, are the three fabrication cubicles. The first cubicle contains the vibratory compaction apparatus and the automatic welder, the second the ultrasonic cleaner, and the third the gamma-ray densitometer and helium leak detector vacuum chamber. Directly over the first two cubicles on the second level is the glove maintenance area. Access into the powder preparation shaft is through a shielding door in the side of the shaft opening into the maintenance area. Access to the fabrication cubicles is through roof hatches opening into the same area. The detailed design features of the equipment installed in this area have been reported by Sease et al. (1)

The manual operations in the facility are accomplished by using either gloved hands or castle joint manipulators. Each piece of equipment was so

Kilorod Solids Preparation and Rod Fabrication Facility.

designed that control is primarily electrical; thus the manual operations consist of transfers from one item to another. The powder preparation equipment requires the use of gloved hands in the positioning of valves and in charging and discharging the ball mill. The compacted rod is transferred by the castle joint manipulators.

The operation of the facility was separated into periods by two different mechanisms: (1) the production of a shipment numbering 120 finished rods and (2) the processing of approximately 100 kg of fuel.

The fuel processing separation occurred at the convenience of the fuel preparation plant and were designated campaigns. At the end of each campaign the system was remotely cleaned, a material balance made, and the operating history critically reviewed. Any procedures requiring modification were performed at this time and were initiated in the next campaign.

EQUIPMENT PERFORMANCE EVALUATION

The major portion of the equipment alterations was performed during the operation with the stand-in oxide; however, other repairs or modifications were performed during the operation with ^{233}U . The remote ball mill (Fig. 4) continued to give trouble and was repaired 10 times during the

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Ball Mill

first two months of operation. The remote ball mill was eventually replaced with one of much simpler design and operable through gloves. The cause of the malfunctioning of the remote mill was the escape of powder from the system causing excessive wear of bearings and sliding surfaces. The remainder of the powder preparation equipment operated with ^{only} ~~nothing more~~ ~~than~~ periodic maintenance.

A number of alterations, adjustments, and repairs on the vibratory compaction equipment (Fig. 5) were required. The polyurethane dust boot between the vibratory feeder tube and the funnel was removed so that the powder feeding into the rod could be observed. Although this increased the dusting in this area, it was found that the feed rate could not be adequately controlled unless the stream was observed. After the high forces, imparted by the vibrator, broke the rack, the rack and pinion gear static-load rider rod was replaced with a weighted rod. The comactuated sliding taper jaw chuck also suffered from these same forces and was replaced with a chuck consisting of a slightly modified Swagelok coupling. Very careful design of components such as these is required to minimize sharp corners, drastic changes in thickness, and other such stress risers as the Branford*

*Manufactured by the Branford Company, New Britain, Connecticut.

Vibratory Compaction Assembly

vibrator, which imparts reported accelerations from 20,000 to 100,000 times the acceleration due to gravity.

The end cap welding machine (Fig. 6) operated practically trouble free, requiring only regular replacement of the tungsten tip. The mechanical forepump operated continuously for more than eight months when the seals seized, requiring replacement.

The density scanner (Fig. 7) performed adequately but not up to the *design expectations* quality expected when designed. The instrumentation was provided with an integrator circuit to measure the area under the plotted density curve thereby allowing the bulk density of the fuel bed to be determined. The output of the detector-photomultiplier was found to be unstable over a long period of time which would not allow the integrator to establish a base line for measurement. The cause of this instability is still being debated. The density variation within the fuel column was determined by running a set of standards with each rod and comparing the standards with the rod. Two typical scans are presented in Fig. 8. The separation between the standards is used to determine the number of chart divisions over which the fuel column scan may range and still meet the specification of $\pm 2\%$ of the bulk density variation within an individual rod.

END PLUG PRESS

TORCH

WELDING CHAMBER

ELEVATOR

End - Cap Welding Machine.

Gamma Scanner.

PROCESS RESULTS

The end product of the Kilorod operation was the production of 1100 fuel rods containing over 878 kg of fuel. It was necessary to compact 1191 rods to get 1100 specification grade rods; 8.2% of the total rod production was recycled. The term recycle is used, as both the hardware and fuel were recovered and reused from a rod not meeting specifications. The recycle rate during the early campaigns was near 20% and ranged to a low of < 1% (1 rod out of 120) in the later campaigns.

The sole cause of recycling of the compacted rod was for excessive variation of the density within a rod as determined by the gamma scanner. One area of needless concern was in the final end closure weld where no trouble was experienced.

The maximum transferrable contamination was specified at 2000 dis/min/cm². The rods were routinely cleaned to approximately one-tenth of this value.

INVENTORY OF MATERIAL

The operation of the facility was divided into seven campaigns encompassing the processing of approximately 100 kg of feed material. In the period between campaigns, the system was remotely cleaned, a running material balance developed, and the past operations critically reviewed.

The material balance data are presented in Table I. The net loss of 0.31% for campaign No. 6 was calculated prior to the complete cleanup of the system; so the final value will be somewhat lower than this. All of the material removed from the system not fabricated into rods has been reprocessed to recover the ^{233}U . These values illustrate one advantage gained in using the unique powder preparation method, as 90% of the powder processed was fabricated into rods while the overall utilization of the powder was 95%.

The shipping cask had a capacity of 120 long or 240 short rods. The condensed data on the rods, divided into shipments, are presented in Table II.

MANPOWER AND PROCESS

As one of the purposes of the operation of the facility was to gain engineering data to establish base line data for the evaluation of other facilities, a time and motion study was performed. The following information has been extracted from that study (2).

The manpower required to operate the facility was one supervisor and three technicians. A total of 28 subroutines composed of over 200 elements were divided among these men and elemental time values determined for each.

Table I. Material Balance Data

Campaign Number	Grams in Rods	Analytical Sample (g)	Floor Sweeping (g)	System Holdup (g) ^a	Total Accountable Grams	Total Grams Received	Net Loss %
1 (230 rods)	208,350	12,000	16,495	35,853	272,698	273,000	0.11
2 (374 rods)	338,548	18,500	24,066	11,615	392,729	393,305	0.15
3 (502 rods)	455,146	24,500	28,503	14,590	522,739	523,500	0.15
4 (720 rods)	652,819	35,500	36,703	22,555	747,577	749,925	0.31
5 (900 rods)	816,902	44,500	39,718	14,390	915,510	916,620	0.12
6 (1100 rods)	878,718	46,500	43,888	11,917	982,023	985,210	0.32

^aThese figures include the fuel in five archive rods as well as the usable material reclaimed at the end of each campaign.

Table II. Condensed Shipping Data

Shipment Number	Grams in Shipment	Total Grams Shipped	Average Density in Shipment	Total Average Density	Grams per Rod
1 (120 rods)	108,757	108,757	9.00	9.00	906
2 (240 rods)	108,576	217,333	8.93	8.97	905
3 (360 rods)	108,492	325,825	8.91	8.94	904
4 (480 rods)	109,287	435,112	8.98	8.95	908
5 (600 rods)	109,182	544,294	8.97	8.95	905
6 (720 rods)	108,525	652,819	8.94	8.95	904
7 (840 rods)	108,732	761,551	8.96	8.95	906
8 (900 rods)	54,541	816,092	8.99	8.96	909
9 (1100 rods)	62,626	878,718	9.04	8.97	313

Table III. Kilorod Subroutines

Table III. Kilorod Subroutines				Time in Minutes at 100% Effectiveness										
Sub-Routine Number	Assign- ment		SUB-ROUTINE	Sub-Routine Cycle				Daily Time (Maximum Routine Included)						
	Present	Proposed		Number of Rods	Per Rod		7-Rod Schedule		10-Rod Schedule		15-Rod Schedule			
					Calendar	Work	Calendar	Work	Calendar	Work	Calendar	Work	Calendar	Work
0	W	W	Energize equipment; pick up liquid nitrogen	DO ¹	12.	12.	1.71 ²	1.71 ²	12.	12.	12.	12.	12.	12.
1	M	S	Load in shipping cask - one man	120	12.	12.	.1	.1						
2	M	L	- other man	120	9.	9.	.08	.08						
3	B	B	Jaw crusher	11	8.45	5.95	.77	.54	8.45	5.95	8.45	5.95	16.9	11.9
4	B	B	Recycle	11	21.9	21.9	1.99	1.99	21.9	21.9	21.9	21.9	43.8	43.8
5	B	B	³ Ball Mill -16 fraction into fines	8	145.2	10.2	9.10 ⁴	.93	--	--	145.2	10.2	145.2	10.2
6	B	B	Ball Mill -6/+16 fraction into fines	10	432.1	12.1	.40	.37	13.2	12.1	13.2	12.1	13.2	12.1
7	B	B	Blend; transfer bottle loading	1	11.2	8.2	11.2	8.2	78.4	57.4	112.0	82.0	168.	123.
8	B	B	Sample (-168 -6/+16 fractions)	10	5.	5.	.5	.5	5.	5.	5.	5.	10.	10.
9	M	L	Seal samples	10	1.	1.	.1	.1	1.	1.	1.	1.	2.	2.
10	B	B	Dispose of old bag (powder preparation cubicle)	10	2.1	2.1	.21	.21	2.1	2.1	2.1	2.1	4.2	4.2
11	M	L	Seal old bag	10	1.	1.	.1	.1	1.	1.	1.	1.	2.	2.
12	L	L	Compacting	1	16.7	7.5	16.7	7.5	116.9	52.5	167.	75.	250.5	112.5
13	W	W	Transfer plugged rod for scanning	1	.9	.9	.9	.9	6.3	6.3	9.	9.	13.5	13.5
14	S	14	Scanner check	1	9.8	4.6	9.8	4.6	68.3	32.2	98.	46.	147.	69.
15	W	W	Welding	1	15.5	11.5	15.5	11.5	108.5	80.5	155.	115.	232.5	172.5
16	W	W	Ultrasonic cleaning	5	39.45	13.95	7.89	2.79	78.9	27.9	78.9	27.9	118.4	41.9
17	W	W	Dry, leak test, and weight	5	18.3	15.5	3.66	3.1	36.6	31.	36.6	31.	54.9	46.5
18	M	L	Turco cleaning	10	10.7	10.7	1.07	1.07	10.7	10.7	10.7	10.7	21.4	21.4
19	M	B	Smear - smear man	10	8.4	7.8	.84	.78	8.4	7.8	8.4	7.8	16.8	15.6
20	M	L	- cubicle man	10	6.2	6.2	.62	.62	6.2	6.2	6.2	6.2	12.4	12.4
21	M	S	Assemble hanger & load in carrier - hanger man	10	13.1	8.65	1.31	.87	13.1	8.65	13.1	8.65	26.2	17.3
22	M	B	- carrier man	10	13.45	13.	1.35	1.3	13.45	13.	13.45	13.	26.9	26.
23	B	L	Mark, weight, & record empty rod	5	15.	15.	3.	3.	30.	30.	30.	30.	45.	45.
24	W	W	3-piece rod end assembly	20	6.	6.	.3	.3	6.	6.	6.	6.	6.	6.
25	M	L	Remove and dispose of cleaning pads	50	10.	10.	.2	.2	10.	10.	10.	10.	10.	10.
26	M	S	Load shipping cask - one man	120	12.	12.	.1	.1						
27	M	L	- other man	120	9.	9.	.08	.08						
Total Time (excluding routines 1,2,26,&27) =							89.22 ²	53.18 ²	656.4	441.2	964.2	549.5	1398.8	840.8

¹ DO = The day's output

² Based on 7 rod day; 1.2 for 10-rod gives 88.71/52.67;
.8 for 15-rod gives 88.31/52.27.

³ Ball milling done overnight and unattended.

⁴ Ball milling attended maximum of twice a day (plus one -6/+16 fraction ball milling) to produce fines to meet maximum schedule.

Crew Time					
"0"					
178.4	106.4	187.5	126.1	7-Rod Day	
253.5	150.5	10-Rod day	275.5	157.	
378.5	224.	15-Rod day		399.7	240.2

Table III presents the subroutines and the time required for each.

Figure 9 shows the distribution of the subroutines among the men and the average distribution for the entire crew. The man labelled "S" was the operating supervisor and could spend approximately one-half time in the rod fabrication portion of the facility.

Figure 10 shows the analysis of the operating log book. The table presents the causes of the downtime experienced as well as the amount of time demanded for each. In the first shipment, for example, it was necessary to repair the ball mill 14 times involving a total of 136 hr. As mentioned previously, the remote mill was exchanged and the ball mill does not reappear until the eighth shipment and then only required 4 hr for repair. The crew and process effectiveness for each shipment are also presented along with a sample calculation of the effectiveness.

The effectiveness values reflect the percent of the time required to fabricate 120 rods that was actually spent producing rods with an additional factor to take care of the recycle rods also handled. Several factors contribute to lowering the effectiveness, the major one being the time spent in equipment maintenance or repair. A low effectiveness value does not necessarily reflect poorly on the performance of the crew or process; however,

SUB-ROUTINE TIME FOR 7-ROD DAY

Figure 9

1

² Replace scanner tube

² Cask Process Days = Cask Total Days - Campaign Days, e.g., 54-1 = 53, Cask Process Days.

³ Rework Days = (Cask Total Days - Lost Work Time Days) $\times \frac{\text{No. of reworks}}{120 + \text{No. of reworks}}$, e.g., (54-15.2) $\times \frac{43}{120 + 43}$ = 10.2, Rework Days.

⁴ Cask Crew Days = (Cask Total Days - Lost Work Time Days) $\times \frac{120}{120 + \text{No. of reworks}}$, e.g., (54 - 15.2) $\times \frac{120}{120 + 43}$ = 28.6, Cask Crew Days.

⁵ Crew Effectiveness = $\frac{\text{Effective Cask Days at rod schedule}}{\text{Cask Crew Days}} \times 100$, e.g., $\frac{8.35 \text{ (7-rod day)}}{28.6} \times 100 = 29\%$

⁶ Process Effectiveness = $\frac{\text{Effective Cask Days at rod schedule}}{\text{Cask Process Days}} \times 100$, e.g., $\frac{8.35 \text{ (7-rod day)}}{53} \times 100 = 16\%$

some cause of extended off-stream time should be clear to explain the low value.

The process effectiveness ranged from a low value of 16% in the first shipment to a high value of 76% in the seventh. Two things contributed to the low value: (1) frequent repair of the ball mill and (2) the large number of recycle rods, 43, required. The high value in the seventh shipment was characterized by a small amount of downtime and few recycle rods.

RADIATION MONITORING

The normal radiation monitoring program at ORNL was expanded to include the use of finger rings and film packs where the work was of such nature that the film badges or pocket dosimeters might not accurately reflect the dose to extremities. These cases were where the most work was performed through the gloves and also where the closest physical contact with the fuel occurred.

The total body exposures which were experienced during the operating period are presented in Table IV. These values show that, operating in this type facility with this type and concentration of fuel, the total body dose was less than one-tenth of the maximum permissible dose for one year. The finger rings and accessory film packs showed similar results.

TABLE IV. Total Body Exposure Data from ORNL Film Badges and Pocket Meters

Rod Fabrication	Total Body Exposure (millirem)											
	3rd Quarter, 1963				4th Quarter, 1963				1st Quarter, 1964			
	Film Badge		Pocket Meter		Film Badge		Pocket Meter		Film Badge		Pocket Meter	
	Total	Av Weekly	Range of Daily Value	Max Weekly	Total	Av Weekly	Range of Daily Value	Max Weekly	Total	Av Weekly	Range of Daily Value	Max Weekly
B	150	12	0-20	40	250	19	0-10	30	350	27	0-30	55
L	230	18	0-60	60	290	22	0-15	45	270	21	0-30	75
S	310	24	0-25	55	200	15	0-20	35	220	17	0-30	60
W	170	13	0-30	50	120	9	0-10	35	160	12	0-15	30

At the end of the normal production operation, one high-radiation-level batch of material (10 kg) was prepared from aged feed material to represent fuel containing 800 ppm ^{232}U in the ^{233}U . Five rods were produced using this material, and the exposure data compared with the normal data are contrasted in Table V. The hands and forearms received the highest exposures, indicating that this type fuel might be processed at 800 ppm ^{232}U ; however, reassignment of work duties might be required to prevent overexposure of the operators. Interpretation of this meager data is subject to risk as the cell background, due to system holdup, has not equilibrated and would probably increase as more material was processed.

ECONOMICS

The operation of the facility offered an opportunity to explore the design, operational problems, and costs of remote fabrication. A number of circumstances prevented this experience from being definitive with regard to true production costs; for example:

1. The amount of floor space and cell layout already existed, and the equipment had to be designed and arranged to fit within this facility.
2. The total time allotted for completion of the job and the money budgeted for development and construction did not allow for optimization.

TABLE V. Comparison of High Level and Normal
Radiation Exposure Data

	High Level (millirem) ^a	Normal (millirem) ^a
Finger Rings	2040	102
Total Body	60	18
Sleeve Film	198	-

^aFigures for one week.

3. The relatively small quantity of fuel handled and the extremely low ^{232}U contamination level made it possible to employ 4 in. of steel for gamma shielding, use glove ports, and permit personnel entry into the cell area for short periods.

Thus, the question of how expensive minor adjustments, repairs, and maintenance will be in a completely remote system was not answered. Despite these unfortunate drawbacks, some very useful and enlightening information has been obtained.

Detailed analysis of the operator routines, determined in the time and motion study, showed that assignment of additional operating personnel would not greatly increase the production rate of the facility. When personnel are added, increases in delay time and nonwork time tend to offset their productivity. If the manpower utilized is at 100% effectiveness and the equipment is on stream 100% of the time, an average of 15.5 acceptable fuel rods per shift can be produced. The operating experience indicates that the facility can be expected to be on stream approximately 80% of the time, 20% of the time being consumed in equipment maintenance, repair, and routine housekeeping functions required for safe operation. These figures show that an average of 12.4 acceptable fuel rods per shift should be maintained.

To attach a realistic cost to the product, it is necessary to remove the facility from the ORNL environment and envision the cost if constructed as a privately financed plant that is part of a nuclear power station complex. The capital, operating, and hardware costs are itemized in Fig. 11. The cost of producing each rod is \$124.40.

If it were possible to do the same job in a facility designed for operation with natural UO_2 , the cost breakdown would be as shown in Fig. 12. The differences are attributable to the fact that a natural UO_2 facility does not have shielded cubicles, which add to the cost, nor does it impose cumbersome manipulation upon the operators. From such small-scale operations, it is evident that there is an increase of 60% for capital outlay and an increase of 40% on operating charges, which give a total penalty of 50% for remote fabrication when the hardware costs are not included.

CONCLUSIONS

The engineering technology required for the recycling of $\text{UO}_2 + \text{ThO}_2$ powder filled fuel rods has been demonstrated by the production of 1100 fuel rods containing over ^{878 kg} 878,000 g of fuel. The powder was densified to 90% of the theoretical particle density using a pneumatic vibrator with only 8.2% of the total rods requiring recycling. The recycle work was entirely due to variations in density along the fuel column in excess of $\pm 2\%$ of the bulk

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COSTS IN A $\text{ThO}_2\text{-U}^{233}\text{O}_2$ FABRICATION PILOT PLANT

COST ITEM	ANNUAL EXPENSE (\$)	\$/ROD	\$/kg OF U + Th	\$/ft OF FUEL
CAPITAL	84,000	27.10	34.10	7.78
OPERATING	210,000	67.70	84.90	19.36
HARDWARE (TUBING, ETC.)		29.60	37.10	8.46
TOTAL		124.40	156.10	35.60

COSTS IN A PILOT PLANT DESIGNED FOR NATURAL UO_2 FABRICATION

COST ITEM	ANNUAL EXPENSE (\$)	\$/ROD	\$/kg OF U + Th	\$/ft OF FUEL
CAPITAL	48,000	16.90	21.20	4.83
OPERATING	150,000	48.40	60.60	13.82
HARDWARE (TUBING, ETC.)		<u>29.60</u>	<u>37.10</u>	<u>8.46</u>
TOTAL		94.90	118.90	27.11

density in the rod being examined, as determined with a gamma-ray densitometer.

The equipment design has been, in general, validated by its trouble-free performance during the operating period. Only one item, the remotely operated ball mill, continued to require large amounts of maintenance and was finally replaced. The malfunction of this item was not so much due to mechanics as to the change in the fuel-particle size required while operating with the binary-size distribution. Schedules for the periodic replacement of critical parts of the chuck mechanism were developed as these parts suffered under the extreme forces due to the high accelerations imparted to the chuck and rod by the pneumatic vibrator.

The rod fabrication process, after the start up, was easily operated and the rod production rate met, and at times exceeded, the design rate of 15 rods/day. The ease of operation was in a great part due to the unique method of production of the fine-particle-size fraction. It is felt that this method could be used with other ceramic-type fuels; however, densification with a pneumatic vibrator would probably be required.

The minimum manpower requirements for the facility were determined at three operators and a half-time supervisor. At this manpower level, the operating effectiveness was determined to be near 60% to maintain an average production rate of 10 rods/day. An exceptionally able crew is necessary to maintain the 60% figure.

The radiation exposure history compiled shows that (Th-3 wt % ^{233}U) O_2 contaminated with 37 ppm ^{232}U may be processed with no danger of over-exposure in the facility. The high level seen indicates that higher levels of contamination could be handled, but no definite figure may be reliably stated on the meager data gathered.

REFERENCES

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