OAK RIDGE NATIONAL LABORATORY LIBRARIES
3 4456 0549114 3
CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION

OAK LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-1501

1

REMOTE FABRICATION OF THORIUM FUELS

J. D. Sease
R. B. Pratt
A. L. Lotts

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this document, send in name with document and the library will arrange a loan.

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

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 that 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.

ORNL-TM-1501

Contract No. W-7405-eng-26

METALS AND CERAMICS DIVISION

REMOTE FABRICATION OF THORIUM FUELS*

J. D. Sease, R. B. Pratt, and A. L. Lotts

For presentation at the Second International Thorium Fuel Cycle Symposium, Gatlinburg, Tennessee, May 3–6, 1966

APRIL 1966

*Research sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.

OAK RIDGE NATIONAL LABORATORY LIBRARIES

3 4456 0549114 3

REMOTE FABRICATION OF THORIUM FUELS

J. D. Sease, R. B. Pratt, and A. L. Lotts

ABSTRACT

A very important part of the development of an economical fuel cycle for thorium-base fuel is the fabrication of the reprocessed fuel into fuel elements. To fabricate large quantities of recycled ^{233}U and thorium fuel, remote fabrication will be required because of the penetrating radiation caused by the presence of ^{232}U in ^{233}U. This paper outlines the problems of remote fabrications and describes the approach taken at ORNL to develop suitable systems for remote fabrication. This is illustrated by a discussion of the oxide fabrication line that was designed for operations in the heavily shielded Thorium-Uranium Recycle Facility now under construction. The design and development of a remote fueled-graphite fabrication line, which is now in progress, is also discussed briefly. The paper concludes with an economic analysis of the consequences of remote fabrication. This analysis shows that the ratio of the cost of remote-to-hooded fabrication is inversely related to plant capacity.

INTRODUCTION

Various reactor systems using thorium-^{233}U are under development because of their potential for achieving low power costs and high fuel utilization.[1,2] The actual achievement of sufficiently low power costs in these reactors will depend to a large extent upon the economics of recycling their fuel. In any recycle scheme, direct costs are incurred for head-end processing, chemical processing, reconstitution of fuel, and fuel refabrication. There is no doubt that the refabrication of thorium fuels into new fuel elements will contribute substantially to the cost of the recycle scheme. The refabrication cost, however, which will have to be based on adequate pilot scale experience, is not now

available; therefore, the development of refabrication technology to a point that will permit accurate assessment of this cost is a most important objective.

Unfortunately, in fabricating fuels containing ^{233}U and thorium, we must contend with significant quantities of penetrating radiation. In the case of refabrication of ^{233}U after Thorex processing with virgin thorium, the penetrating radiation is caused primarily by ^{232}U, which is formed along with the ^{233}U during the conversion of thorium in the reactor. The amount of ^{232}U in ^{233}U is dependent upon the neutron energy distribution in the reactor and the amount of total exposure[3] that has been experienced by the fuel. The ^{232}U decay is shown in Fig. 1; the major contributors to the radiation are ^{212}Bi and ^{208}Tl, which both emit hard gamma radiation.

In equilibrium cycle fuel, the ^{232}U in total uranium is expected to range from 500 to 800 ppm for reactors now under consideration. This quantity of ^{232}U is sufficient to require remote fabrication in plants of a significant size.[3–5] If irradiated thorium is recycled along with the ^{233}U, the radiation from the decay of ^{228}Th and ^{234}Th makes remote fabrication mandatory at any practical production level.

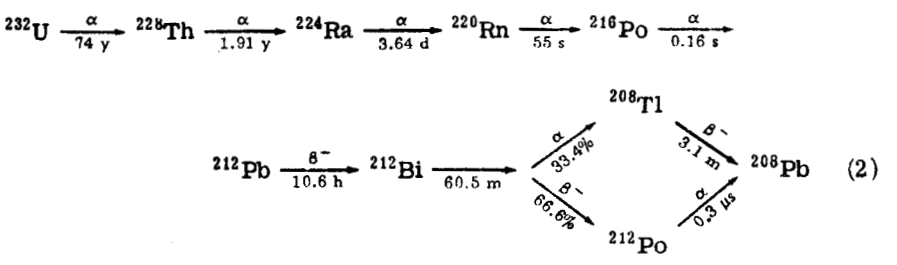


Fig. 1. The ^{232}U Decay Chain. Ref. E. D. Arnold, "Radiation Hazards of Recycle U^{233}-Thorium Fuels," p. 259 in Proceedings of the Thorium Fuel Cycle Symposium, Gatlinburg, Tennessee, December 5–7, 1962, TID-7650 Bk 1 (July 1963).

Development of remote technology for the thorium fuel cycle is a major objective of the Thorium Utilization Program at the Oak Ridge National Laboratory. The development of the ORNL sol-gel process for preparing ThO_2-UO_2 shards or microspheres[6] has established a firm starting point for this technology. The design, construction, and operation of the semiremote Kilorod Facility for the fabrication of 1100 rods of ThO_2–3% $^{233}UO_2$ on a pilot plant scale was an important step toward this goal.[7] The heavily shielded Thorium-Uranium Recycle Facility (TURF),[8] which is now being constructed, will provide space for the development of remote fabrication techniques for thorium-base fuels. We have essentially completed the design of equipment for remotely fabricating oxide fuels by vibratory compaction in the TURF. Currently, we are designing equipment for the remote fabrication of graphite fuels containing thorium-uranium oxide or carbide fuel coated with pyrolytic carbon.

In this paper, we shall present our analysis of the problems involved in refabrication, our approaches to refabrication problems, and our projection of the economic consequences of refabrication.

ANALYSIS OF FABRICATION PLANT DESIGN FOR RECYCLE OF FUEL

Our analyses of commercial refabrication plants for processing thorium-base fuels have indicated that remote fabrication will be necessary for fabricating fuels containing equilibrium cycle material, even if virgin thorium is mixed with the bred ^{233}U. This conclusion is based on detailed analysis of plants for processing fuels for the Spectral Shift Control Reactor (SSCR), Heavy-Water Organic-Cooled Reactor (HWOCR), and the High-Temperature Gas-Cooled Reactor (HTGR).[5]

We shall illustrate our basis and method of analysis with reference to plants for fabricating HTGR fuel elements containing pyrolytic-carbon-coated thorium-uranium carbide microspheres. The HTGR fuel fabrication flowsheet is shown in Fig. 2. For analytical purposes, the facility was divided into three zones:

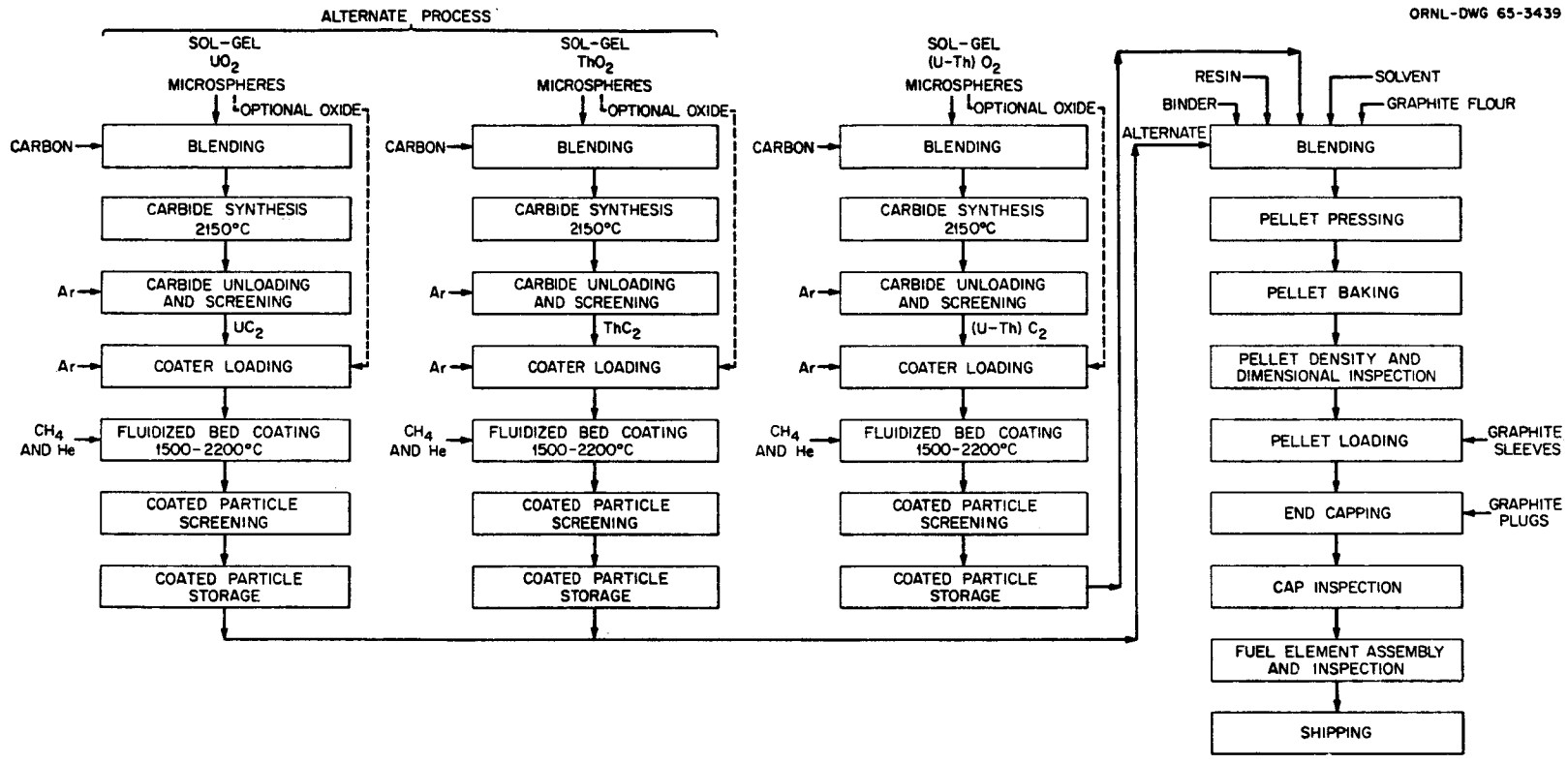


Fig. 2. Flowsheet for Fabrication of HTGR Fuel Elements.

Zone 1: The oxide microspheres are received from the fuel reconstitution facility, converted to carbide, and inspected.

Zone 2: The fuel particles are coated with pyrolytic carbon and inspected.

Zone 3: Compacts are prepared, inspected, and loaded into the graphite sleeves. Finally, two fuel segments are assembled together, the end pieces inspected, and shipped to the reactor site. Table 1 shows the material location, quantity, and age in the fabrication plants processing the $(Th,U)C_2$ fuel.

Table 1. The Quantity and Age of Material in the Zones of Fabrication Plants Processing $(Th,U)C_2$ Fuel

Zone	Plant Capacity (kg/day)	Material in Process (kg)	Age of Process Material (days)	Holdup (kg)	Age of Holdup Material (days)
1	60	22	5.7	3	10.7
	230	88	5.7	3	10.7
	930	352	5.7	3	10.7
	3700	1408	5.7	3	10.7
2	60	20	6.1	3	11.1
	230	80	6.1	3	11.1
	930	320	6.1	3	11.1
	3700	1280	6.1	3	11.1
3	60	15	6.7	3	11.7
	230	30	6.3	3	11.4
	930	60	6.3	3	11.3
	3700	60	6.2	3	11.3

The following assumptions were made in calculating the shielding requirements.

1. The time between solvent extraction and receipt of material at the fuel element fabrication plant is 5 days.

2. A major cleanup of the equipment and enclosures is performed after 5 working days.

3. No substantial quantity of the material is located closer than 1 ft to the enclosure wall.

4. The amount of material retained in the equipment (from the walls, in crevices, etc.) during processing is 3 kg, but the material is released and continued in the process at 5-day cleanup intervals.

5. The plant processes 110% of quantity shipped to allow for internal rejection of products not meeting specifications.

6. The limit of personnel exposure to radiation is 40 mr/week.

The results of shielding calculations are shown in Fig. 3. As can be observed, we used 3.5 in. of steel as a practical limit for semiremote fabrication because of the difficulty of working through a greater distance with gloved hands or tongs. Also, radiation from sources requiring greater than 3.5 in. of steel would prohibit, or at least greatly inhibit, contact maintenance of the equipment. In the case of equilibrium cycle HTGR fuel exposed to approximately 100,000 Mwd/tonne, we might expect from 40 to 70 ppm of ^{232}U in total heavy metal (10 wt % $^{232}UO_2$–90 wt % virgin ThO_2). Even at the lowest predicted ^{232}U level, it is observed from the curves that remote fabrication will be required at any appreciable plant capacity.

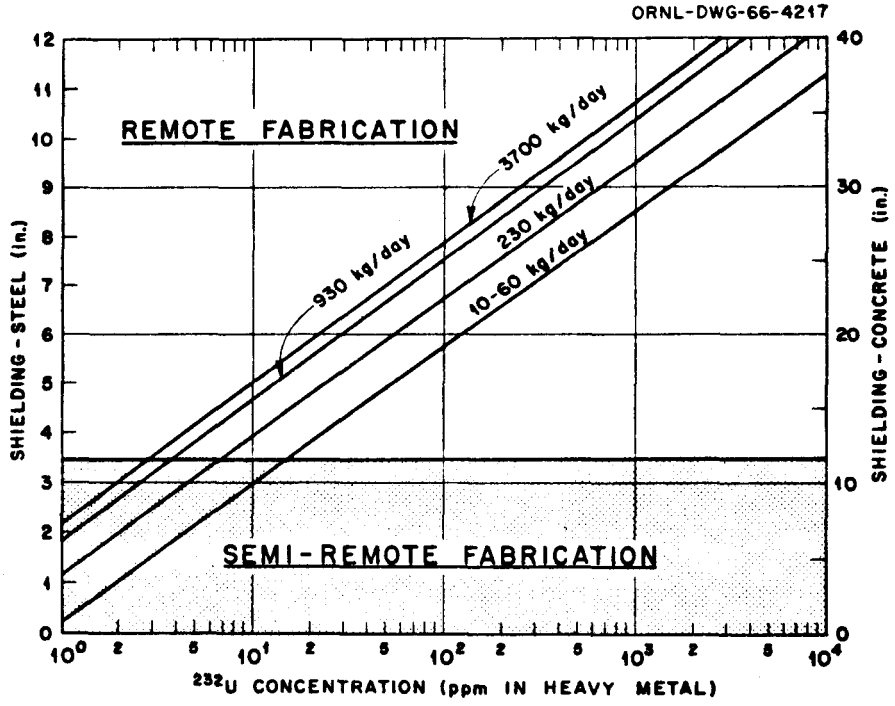


Fig. 3. Shielding Requirements for Plants Fabricating ^{233}U-Bearing HTGR Fuel.

PROBLEMS OF REMOTE FABRICATION

Remote fabrication of fuels poses problems that do not exist in conventional fabrication plants. The complexity of any operation tends to be magnified when the operation is done remotely; the performance of fabrication operations, many of which are performed by hand in conventional facilities, is inherently difficult in remote facilities; and repair of equipment is extremely difficult and consumes more time than in conventional plants.

Most of the problems in remote fabrication are due to the inaccessibility of the process equipment. Manual operations are slow and cumbersome because they must be accomplished either by master slave or by electromechanical manipulators. A comparison of the times required by different systems to perform the simple operation of transferring one fuel rod from one processing station to the next is given in Table 2.

Table 2. Transfer Times in Fabricating One Fuel Rod

Type Transfer	Number of Transfers	Time per Transfer (min)	Total Transfer Time (min)
Contact	12	1.0	12
Manipulator	12	5.0	60
Automatic	12	0.5	6

The values listed are based on actual transfer time, but they do not include the time to uncouple and couple the rod at the stations. This example illustrates that to attain high use factors for the equipment and manpower in remote operations, most of the process equipment must be designed for automatic operation.

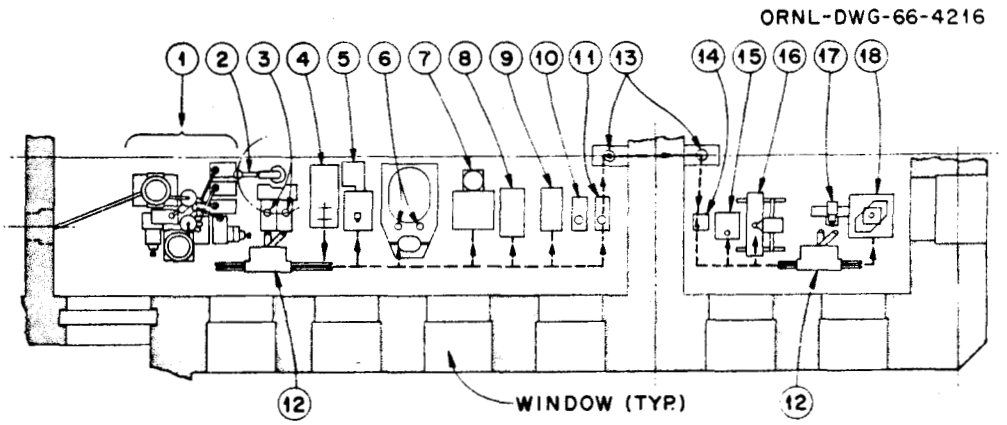
Maintenance in a remote fabrication plant is certainly one of the major problems. The maintenance philosophy that is actually selected depends upon the contamination level in the area that is occupied by

the equipment. Equipment in fabrication cells that are highly contaminated by fuel dust (contaminated fabrication) must be maintained in place by the cell manipulators; or the equipment must be removed from the area by a remote cell crane and cleaned before maintenance can be performed in a gloved maintenance area. By contrast, maintenance of equipment used in operations that handle clad fuel (clean fabrication) can be performed by direct means after shielding the source materials; however, this equipment should be designed to facilitate maintenance in order to minimize down-time. These unique maintenance requirements in remote fabrication make the use of specially designed equipment mandatory.

APPROACH TO REMOTE FABRICATION

To lessen the inherent problems of remote fabrication, the fuel element to be fabricated should be designed to simplify and minimize the number of remote operations, and the processes for remote fabrication should be made as simple and straightforward as possible. Mechanical assembly of fuel elements is an example of the type of simplification that is necessary. The Oak Ridge National Laboratory has designed and is building the Thorium-Uranium Recycle Facility to demonstrate remote fabrication of oxide or carbide fuels. Our approach to remote fabrication can be illustrated by considering the process equipment for making oxide-bearing, metal-clad, rod-type fuel elements in the TURF. The conceptual designs were based on the experience we gained in the development and the operation of the semiremote Kilorod Facility.[7,9,10]

The layout of equipment in the oxide line is shown in Fig. 4. The equipment in this process was designed to fabricate fuel rods 2 to 10 ft in length and 1/4 to 3/4 in. in diameter using vibratory compaction, a process that was selected because of its simplicity for remote operations. The equipment was laid out in a modular fashion so that each station is a separate unit completely independent of other items. Each step in the fabrication process is accomplished in a separate station, and a transfer



1. POWDER PREPARATION EQUIP.
2. FUEL TRANSFER MACHINE
3. VIBRATORY COMPACTOR
4. TUBE MAGAZINE
5. CHECK WEIGHER
6. GAMMA SCANNER
7. CAPPING MACHINE
8. WELDING MACHINE
9. LEAK CHECK MACHINE
10. REJECT RACK
11. CLEANING AND TRANSFER BASKET
12. FUEL ROD TRANSFER MACHINE
13. CLEANER TRANSFER MACHINE
14. FUEL ROD BASKET
15. CONTAMINATION MONITOR
16. WELD RADIOGRAPHY MACHINE
17. FUEL ROD DIMENSIONAL CHECK
18. FUEL ELEMENT ASSY. AND INSPECTION MACHINE

Fig. 4. Layout of Equipment for the TURF Oxide Fabrication Line.

device is used to convey rods between stations. In the design of the contaminated fabrication equipment, the requirement for remote maintenance was the major consideration. Each of the 25 major equipment items for the contaminated fabrication cell were designed so that they could be installed and removed separately by the remote handling equipment in the cell.

The various subassemblies of each machine were designed in a modular fashion for removal by the remote handling equipment to facilitate maintenance. In addition, each subassembly was made so that it could be dismantled as easily as possible to further facilitate repair when the subassembly reaches the gloved maintenance area. The vibratory compactor, depicted in Fig. 5, is an example of a type of equipment that was designed for the oxide line.

Similar design principles were used for the clean fabrication equipment; however, complete remote installation and removal capability was not necessary.

ORNL-DWG 65-917

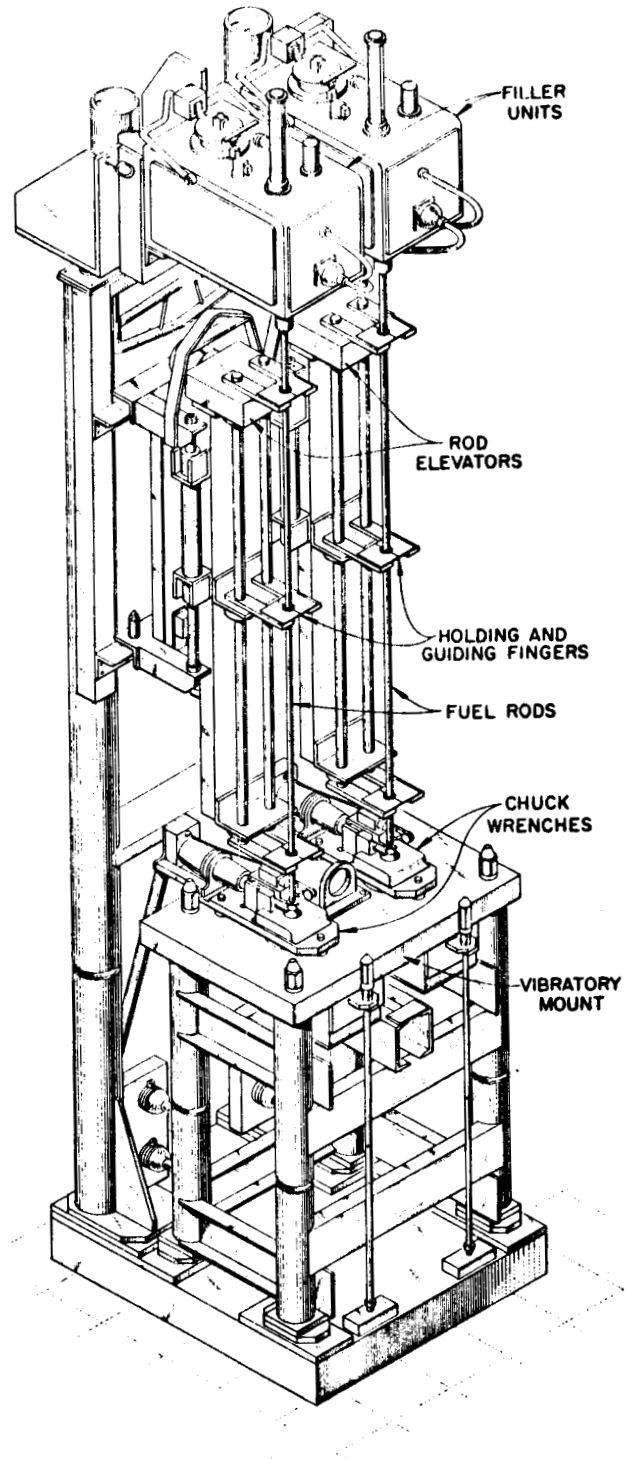


Fig. 5. Vibratory Compactor.

In the oxide fabrication line, it was recognized at the onset of design that automatic control and a central data collection system would be necessary to achieve the desired production rate of 40 rods per 8-hr shift. The general control criteria for the oxide line was that all operations, as far as practicable, should be designed with closed loop control circuits. This was stipulated so that we could be assured that any operation that was initiated actually occurred. The simplest type of closed loop system is a motor circuit with a limit switch. Open loop devices, such as stepping motor circuits or timed actuators, can cause an operation to occur out of sequence by erroneously indicating externally that an operation has occurred when, in fact, it has not.

Figure 6 shows the operating times of processing stations superimposed in the path of the transfer machine in a portion of the oxide fabrication process. The dotted lines indicate alternate paths of the

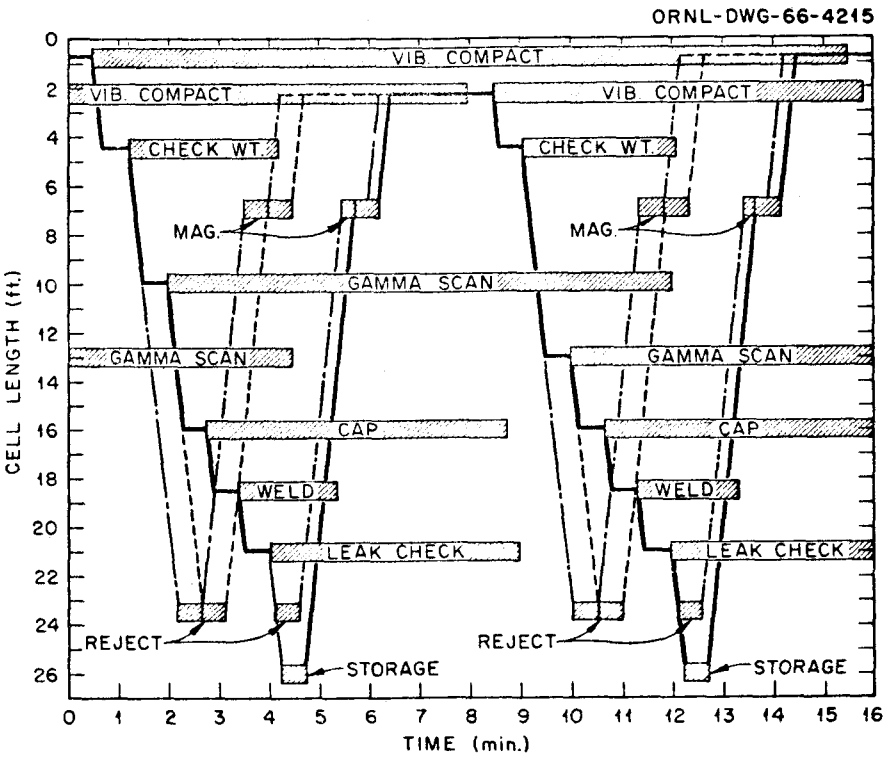


Fig. 6. Operating Times of Processing Stations Superimposed on the Path of the Tube Transfer Machine in a Portion of Oxide Fabrication Line.

transfer device if a rod is rejected during processing. In processing one fuel rod, 12 transfers and approximately 300 separate control operations are required. An example of the control operations of one station in the oxide fabrication line is shown in Table 3. These examples strongly suggest that a logic system is needed to control the overall operations if any appreciable production rate is to be achieved on a reliable basis. In addition, systematic data collection is necessary to detect and record process changes and to provide permanent fabrication records for each rod as it passes through the system. Typical data required for vibratorily compacted fuel pins are:

1. material batch number,
2. empty weight of rod,
3. filled weight of rod,
4. fuel level in rod,
5. gamma scan,
6. leak check,
7. contamination check,
8. dimensional check,
9. element number and position.

On the basis of these requirements, we selected for the oxide fabrication line a process control system consisting of individual station controls that automatically sequence the steps by solid state logic circuitry and a master controller that initiates the operation of individual stations, controls the operation of the transfer device, and serves as the central data collector.

Current Problem in Remote Fabrication

Currently, we are working on the design and development of a fabrication line for the TURF to fabricate fueled-graphite elements containing pyrolytic-carbon-coated fuel microspheres for an HTGR.

Our flowsheet for fueled-graphite fabrication consists of converting sol-gel oxide microspheres to microspheres of carbide, coating these particles with pyrolytic carbon, inspecting the coated fuel particles, loading the particles into compacts, loading these compacts into

Table 3. Control Operations for Vibratory Compactor

Mechanism	Type Motivation	Function	Position	Ready Condition	Operating Sequence	Initiated Sequence	Transfer Interlock
Upper stage elevator	Electric motor	Up	On		18	Step 17	
			Off	x	19	Limit	
		Down	On		6	Step 5	
			Off		7	Limit	
Dust seal	Pneumatic diaphragm	Seal	On		8	Step 7	
			Off	x	17	Step 15	
Feeder	Electrical vibration	Feed	On		11	Step 10	
			Off	x	12	Relay	
Rider rod	Pneumatic cylinder	Tamp and measure	Up	x	15	Step 14	
			Down		13	Step 12	
Fuel receiver	Pneumatic cylinder	Seal	Open	x	Prior to operation		
Fuel receiver	Magnetic vibrator	Shake	On		Prior to operation		
			Off	x			
Rod holder	Electric motor		Open	x	24	Step 23	x
			Grip tight		1 and 16	External and Step 15	x
			Grip loose		9	Step 7	
Chuck motor	Pneumatic motor	Open	On		20	Step 19	
			Off	x	21	Limit	
		Closed	On		4	Step 3	
			Off		5	Limit	
Vibrator	Pneumatic motor	Compact	On		10	Step 9	
			Off	x	14	Time	
Elevator	Electric motor	Up	On		22	Step 21	
			Off	x	23	Limit	
		Down	On		2	Step 1	
			Off		3	Limit	

prefabricated graphite logs, and inspection of the completed fueled-graphite assembly. The two main problem areas in fueled-graphite fabrication are the conversion of $(Th,U)O_2$ to $(Th,U)C_2$ and the application of pyrolytic-carbon coating to the fuel particles. Each of these processes have been carried out on a laboratory scale at ORNL.[11,12] We are currently operating both the coating process and the conversion process on a pilot plant scale to obtain engineering data for design of remote systems.

From the standpoint of remote fabrication, the coating operation appears to be the most difficult step. At this time our principal work is directed toward coating in a fluidized bed. We are currently operating a pilot scale fluidized-bed coating furnace (Fig. 7) to develop operating criteria to scale the coating processes up to 5 kg/batch. Our experience thus far indicates that production of coating of uniform and controlled properties, as well as maintenance of the coating furnace, are difficult even under contact methods of operation. With present design and operating techniques, the internal parts of the coating furnaces require frequent maintenance.

In addition to fluidized-bed coating, we are investigating other coating methods which may be more suitable to remote operation. One approach is the use of a drum coater in which the fuel particles are individually heated while being mechanically agitated in a finned rotating graphite crucible. This system appears to have the possibility of being scaled up to 20 kg/batch size.

Although our effort has been directed primarily toward conversion and coating of particles, there are many other steps in fueled-graphite development that need considerable attention. One of these problems is the consolidation of the coated particles in a graphite matrix without damaging the particle coatings. A simpler process than the current practice of overcoating or mixing with materials for forming a graphite matrix, followed by warm pressing and graphitizing, would be desirable from a remote fabrication standpoint.

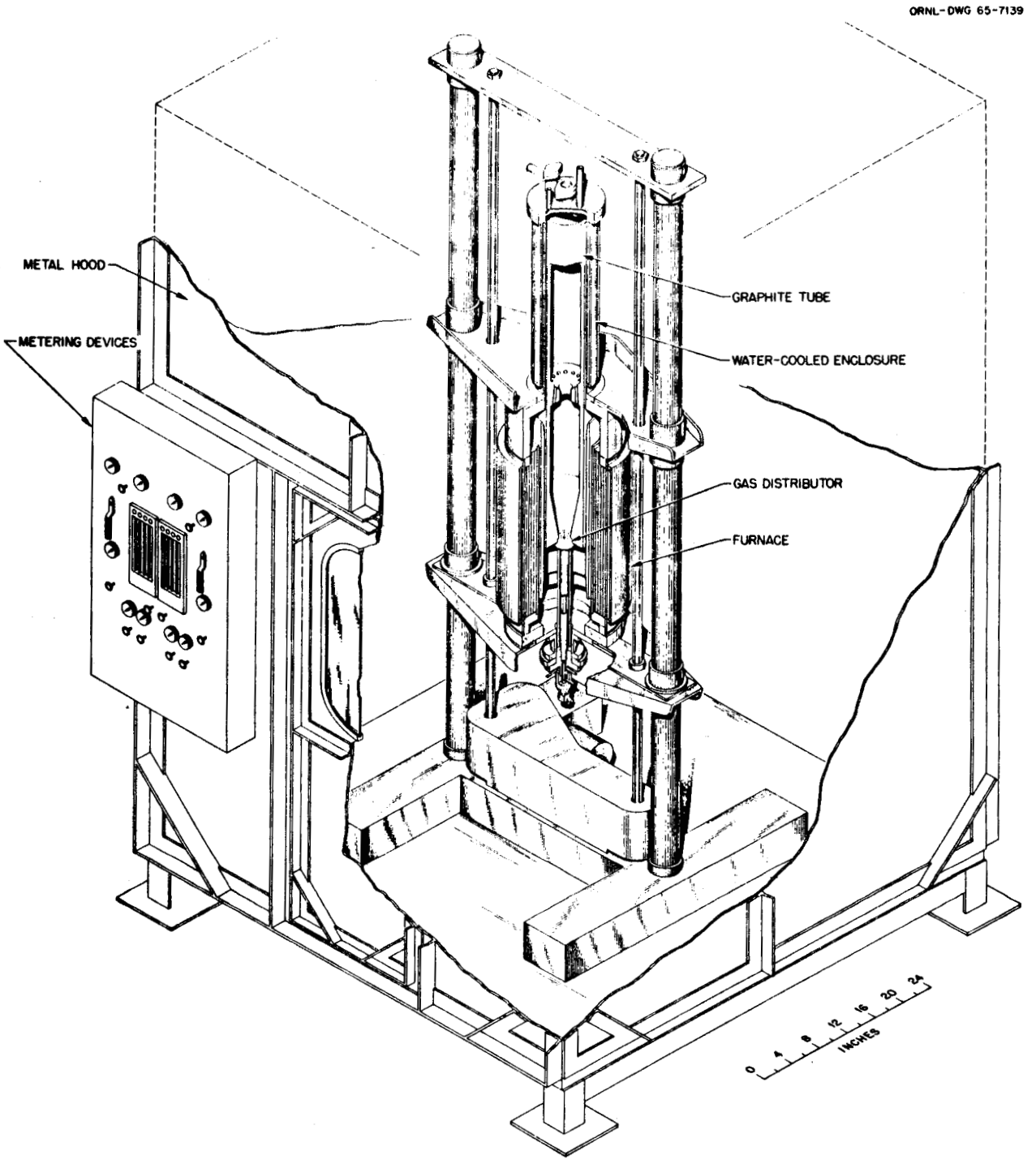


Fig. 7. Pilot Scale Fluidized-Bed Coating Furnace.

ECONOMICS OF REMOTE FABRICATION

In any fuel cycle, the fabrication step contributes a large portion of the direct processing cost. In Fig. 8, which shows the direct costs associated with remote fabrication of the HWOCR[13] and HTGR[2] type fuel, we see that the fabrication step accounts for 45 to 69% of the direct costs. Reprocessing, which includes head-end processing by either burn-leach or chop-leach and solvent extraction, accounts for 26 to 50% of the cost; the fuel reconstitution accounts for approximately 5% of the processing cost. Certainly, remote fabrication will be more expensive than conventional fabrication of nonrecycle fuel because of the increased capital cost for shielding and for automatic equipment, and the additional expense of operating and maintaining equipment. At low plant capacities we expect to pay a high penalty because this increase in capital cost will represent a large portion of the fabrication cost; however, as plant

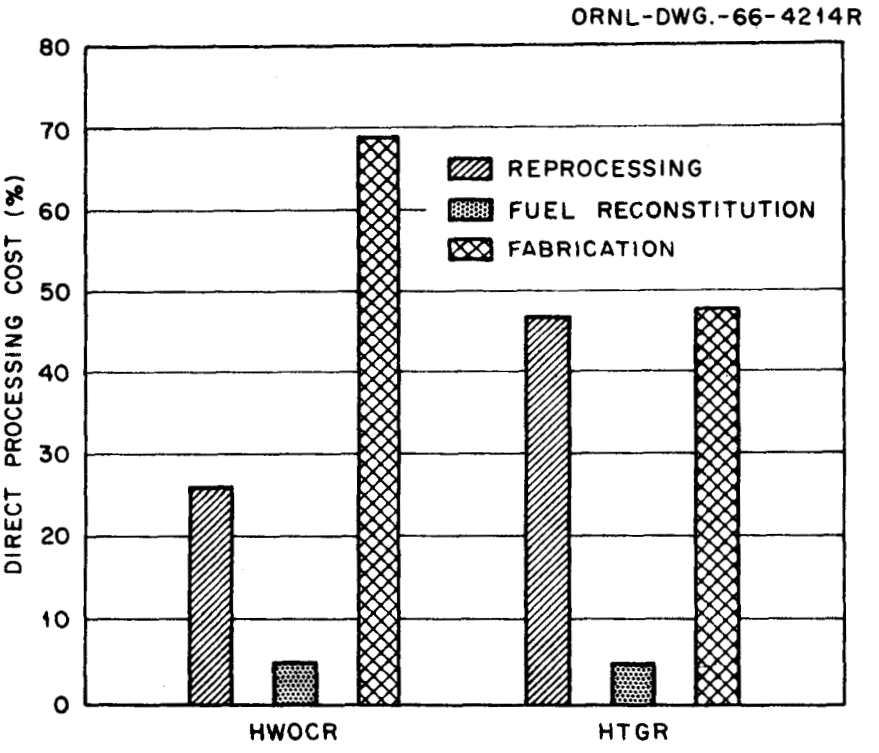


Fig. 8. The Breakdown of the Direct Processing Costs for HWOCR (Oxide-Cluster Fuel) and HTGR (ThC_2-UC_2) Using Remote Fabrication.

capacity increases, the effect of remote fabrication should decrease because of the increased degree of automation that will be required for a high-capacity contact fabrication plant, which is already necessary in a remote plant of a lower capacity.

The effect of the mode of fabrication and production rate on the cost of fabricating the HTGR type fuel element is shown in Fig. 9. As can be seen, the production rate has a substantial effect on the cost of fabrication. Analyses of other fuel element types show similar effects.[5,14]

The cost of remote fabrication can be best demonstrated by the incremental cost factor between the various modes of fabrication. Tables 4 and 5 present respectively the ratio of remote fabrication cost to hooded fabrication for HWOCR and HTGR elements using recycled thorium. The decrease in the ratios with increased plant capacity are due primarily to more efficient utilization of certain service personnel

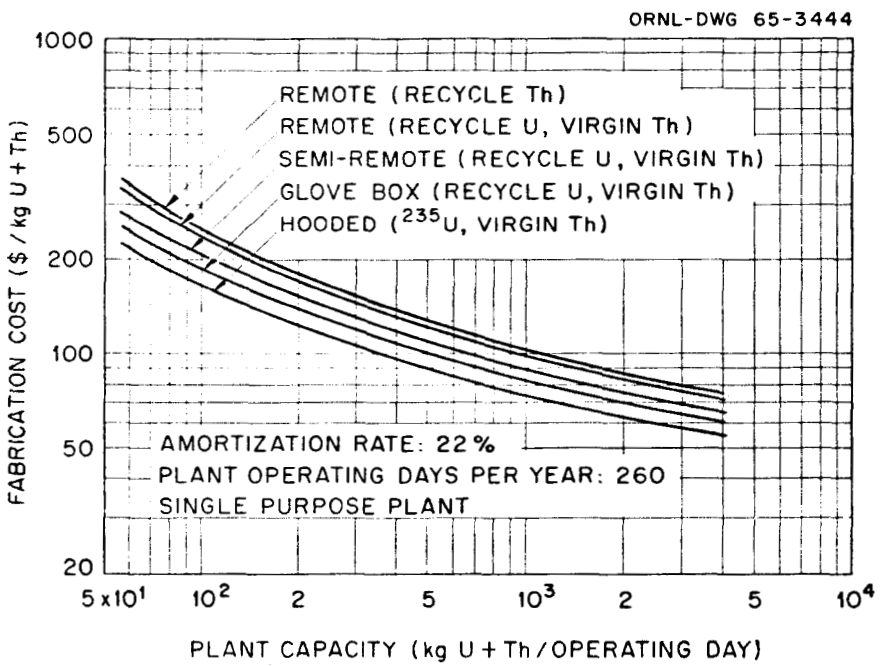


Fig. 9. Effect of Production Rate and Mode of Fabrication on the Cost of Fabricating Fueled-Graphite Elements.

Table 4. Cost Ratios for Comparison of Remote and Hooded Plants Fabricating $(Th,U)C_2$ Particles

	Plant Capacity (kg heavy metal/day)			
	60	230	930	3700
	Ratio of Remote-to-Hooded Cost			
Capital	1.87	1.79	1.73	1.75
Operating	1.47	1.43	1.37	1.37
Total (including hardware)	1.53	1.42	1.34	1.35

Table 5. Cost Ratio for Comparison of Remote and Hooded Plants Fabricating Oxide-Cluster Fuel Elements for HWOCR

	Plant Capacity (kg heavy metal/day)			
	60	230	930	3700
	Ratio of Remote-to-Hooded Cost			
Capital	1.67	1.60	1.53	1.42
Operating	1.28	1.23	1.19	1.15
Total (including hardware)	1.35	1.30	1.22	1.16

and facilities in large remote fabrication plants. The cost ratio for the HWOCR fuel element is lower than for the HTGR fuel element because a greater number of the operations involved in the fabrication of HWOCR fuel elements are done outside the remotely operated facilities and do not incur the penalties. This point can be further illustrated by Table 6, which presents the cost ratio for comparison of remote and hooded plants fabricating fueled-graphite elements containing discrete particles of UC_2 and virgin ThC_2. In this particular case, a great portion of the fabrication (the conversion and coating of virgin ThO_2) is done in hooded facilities.

Table 6. Cost Ratios for Comparison of Remote and Hooded Plants Fabricating UC_2 and ThC_2 Particles[a]

	Plant Capacity (kg heavy metal/day)			
	60	230	930	3700
	Ratio of Remote-to-Hooded Cost			
Capital	1.29	1.20	1.18	1.09
Operating	1.26	1.22	1.18	1.16
Total (including hardware)	1.24	1.16	1.12	1.08

[a]50 ppm ^{232}U in heavy metal; virgin thorium.

SUMMARY AND CONCLUSIONS

From the engineering and development that have been accomplished on oxide fuel element fabrication equipment and from our current study of the equipment for fueled-graphite fabrication, we have drawn the following conclusions. Any process intended for remote fabrication should be simple and should be as short as possible. The fuel element design should be such that the number of operations required for remote handling is minimized and that the fuel element can be easily assembled remotely. The process equipment and its major components should be designed on a modular concept to facilitate maintenance. Automatic machinery should be employed using closed loop controls combined with a central data collection system. If these criteria are followed, our analyses have shown that the ratio of the cost of remote fabrication to that of hooded fabrication is low.

ACKNOWLEDGMENTS

The work represented in this paper is the result of the efforts of the following people whose assistance is gratefully acknowledged: D. A. Douglas for his supervision and direction; T. N. Washburn for his assistance in the analysis of fuel refabrication economics, especially the analysis for the HWOCR; R. L. Pilloton for valuable contribution to economic and technical analyses for refabrication of fueled-graphite elements; H. R. Livesey for graphic arts; and Meredith Hill and Marjorie Clary for preparing this document on a minimal notice.

REFERENCES

1. R. E. Pahler, "Coated-Particle Fuels for Civilian Gas-Cooled Reactors," p. 1, Ceramic Matrix Fuels Containing Coated Particles, Proceedings of a Symposium Held at Battelle Memorial Institute, November 5 and 6, 1962, TID-7654.

2. M. W. Rosenthal et al., A Comparative Evaluation of Advanced Converters, ORNL-3686 (August 1964).

3. E. D. Arnold, "Radiation Hazards of Recycle U^{233}-Thorium Fuels," pp. 253–284, Proceedings of the Thorium Fuel Cycle Symposium, Gatlinburg, Tennessee, December 5–7, 1962, TID-7650, Bk 1 (July 1963).

4. A. B. Shuck, A. L. Lotts, and K. Drumheller, "The Remote Fabrication of Reactor Fuels," Reactor Technology – Selected Reviews – USAEC, 1965.

5. A. L. Lotts and D. A. Douglas, Refabrication Technology for the Thorium-Uranium-233 Fuel Cycle, ORNL-TM-1141 (June 1965).

6. P. A. Haas and S. D. Clinton, Preparation of Thoria and Mixed Oxides Microspheres, ORNL-TM-1281 (November 1965).

7. R. E. Brooksbank, A. L. Lotts, and J. P. Nichols, "The Impact of Kilorod Operational Experience on the Design of Fabrication Plants for ^{233}U-Th Fuels," paper presented at the Second International Thorium Fuel Cycle Symposium, Gatlinburg, Tennessee, May 3–6, 1966.

8. A. R. Irvine, A. L. Lotts, and A. R. Olsen, "The Thorium-Uranium Recycle Facility," paper presented at the 1965 Winter Meeting of the American Nuclear Society, Washington, D. C., November 15–18, 1965.

9. J. E. Van Cleve, Jr., and A. L. Lotts, "Operating Experience in a Semi-Remote Facility for Preparation of Fuel Rods Containing $(U^{233},Th)O_2$," pp. 257–271, Proceedings of the 12th Conference on Remote Systems Technology, American Nuclear Society, Hinsdale, Illinois, 1964.

10. J. D. Sease, A. L. Lotts, and F. C. Davis, Thorium-Uranium-233 Oxide (Kilorod) Facility – Rod Fabrication Process and Equipment, ORNL-3539 (April 1964).

11. R. L. Pilloton, R. L. Hamner, and E. S. Bomar, "Conversion of Sol-Gel Microspheres from ThO_2 to ThC_2," Metals and Ceramics Division Ann. Progr. Rept. June 30, 1965, ORNL-3870, p. 275.

12. R. L. Beatty, F. L. Carlsen, Jr., and J. L. Cook, "Pyrolytic Carbon Coatings on Ceramic Fuel Particles, Nucl. Appl. 1(6), 560–566 (1965).

13. P. R. Kasten et al., Evaluation of Heavy Water Organic Cooled Reactors, to be issued as an ORNL report.

14. A. L. Lotts, D. A. Douglas, Jr., and R. L. Pilloton, Refabrication Technology and Costs for High-Temperature Gas-Cooled Reactor Fuels, ORNL-TM-1115 (May 1965).

INTERNAL DISTRIBUTION

1–2. Central Research Library
3. ORNL – Y-12 Technical Library
Document Reference Section
4–28. Laboratory Records Department
29. Laboratory Records, ORNL R.C.
30. ORNL Patent Office
31. G. M. Adamson, Jr.
32. E. S. Bomar
33. G. E. Boyd
34. R. E. Brooksbank
35. F. L. Culler
36. J. E. Cunningham
37. F. C. Davis
38. D. A. Douglas, Jr.
39. D. E. Ferguson
40. R. B. Fitts
41. J. H Frye, Jr.
42. W. O. Harms
43–45. M. R. Hill
46. P. R. Kasten
47–51. A. L. Lotts
52. H. G. MacPherson
53. A. R. Olsen
54. P. Patriarca
55. R. L. Pilloton
56. J. W. Prados
57. R. B. Pratt
58. J. L. Scott
59–83. J. D. Sease
84. D. B. Trauger
85. T. N. Washburn
86. A. M. Weinberg
87. J. R. Weir
88. R. G. Wymer

EXTERNAL DISTRIBUTION

89. R. E. Pahler, AEC Washington
90–91. D. F. Cope, AEC, Oak Ridge Operations
92. Division of Research and Development, AEC, ORO
93–107. Division of Technical Information Extension