AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

**Cover Sheet for a Hanford
Historical Document
Released for Public Availability**

Released 1994

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISCLAIMER

This is a **historical document** that is being released for public availability. This was made from the best available copy. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, 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.** The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DECLASSIFIED

(CLASSIFICATION)

DOCUMENT NO.

HW-81569

SERIES AND COPY NO.

DATE

April 24, 1964

GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

XX

THIS DOCUMENT CONTAINS RESTRICTED DATA AS
DEFINED BY THE ATOMIC ENERGY ACT OF 1954
ITS TRANSMISSION OR REVELATION OF ITS CONTENTS
TO AN UNAUTHORIZED PERSON IS PROHIBITED.

TITLE

C REACTOR OVERBORE TEST FACILITY REVIEW

☐

OTHER OFFICIAL CLASSIFIED INFORMATION

THIS MATERIAL CONTAINS INFORMATION AFFECTING
THE NATIONAL DEFENSE OF THE UNITED STATES
WITHIN THE MEANING OF THE ESPIONAGE LAWS,
TITLE 18, U.S.C., SECS. 793 AND 794, THE TRANSMISSION
OR REVELATION OF WHICH IN ANY MANNER
TO AN UNAUTHORIZED PERSON IS PROHIBITED BY
LAW.

AUTHOR

P. A. Carlson and
R. Nilson

ISSUING FILE

THIS DOCUMENT IS NOT TO BE DISTRIBUTED OR WHEN UNAUTHORIZED PERSONS HAVE ACCESS
TO IT, IT IS TO BE KEPT IN AN SECURED LOCATION. IT IS TO BE KEPT IN AN SECURED LOCATION
WHILE IN YOUR POSSESSION. IT IS TO BE KEPT IN AN SECURED LOCATION WHILE IN YOUR
POSSESSION. IT IS TO BE KEPT IN AN SECURED LOCATION WHILE IN YOUR POSSESSION.
THIS DOCUMENT IS NOT TO BE DISTRIBUTED OR WHEN UNAUTHORIZED PERSONS HAVE ACCESS
TO IT, IT IS TO BE KEPT IN AN SECURED LOCATION. IT IS TO BE KEPT IN AN SECURED LOCATION
WHILE IN YOUR POSSESSION. IT IS TO BE KEPT IN AN SECURED LOCATION WHILE IN YOUR
POSSESSION. IT IS TO BE KEPT IN AN SECURED LOCATION WHILE IN YOUR POSSESSION.
OF REFERENCE IS PROHIBITED. IT IS NOT TO BE KEPT IN AN SECURED LOCATION.
OF REFERENCE IS PROHIBITED. IT IS NOT TO BE KEPT IN AN SECURED LOCATION.
OF REFERENCE IS PROHIBITED. IT IS NOT TO BE KEPT IN AN SECURED LOCATION.
OF REFERENCE IS PROHIBITED. IT IS NOT TO BE KEPT IN AN SECURED LOCATION.

ROUTE TO:

PAYROLL NO.

LOCATION

FILES ROUTE
DATE

SIGNATURE AND DATE

300 Area Files

R.W. Hopper

300 Area Files

12578

105-C

AUG 12 '64

R.W. Hopper 8/13

REFERENCE COPY
RECEIVED 100- AREA
APR 30 1964
RETURN TO
TECHNICAL INFORMATION FILES

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

(CLASSIFICATION)

DECLASSIFIED

HW-81569

This document classified by:

This document consists of
22 pages. Copy No. 3/
of 32 copies.

This document contains restricted data as
defined in the Atomic Energy Act of 1954.
Transmission or the disclosure of its
contents by any means to any unauthorized
person is prohibited.

C-REACTOR OVERBORE TEST FACILITY REVIEW

By

P. A. Carlson and R. Nilson

April 24, 1964

Classification Cancelled and Changed To

DECLASSIFIED

By Authority of RM Sten

CG-PR-2, 4-13-94

By DK Hanson, 4-17-94

Verified By J E Sawley 4-18-94

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

NOTICE

This report was prepared for use within General Electric Company in the course
of work under Atomic Energy Commission Contract AT(45-1) - 1350, and any
views or opinions expressed in the report are those of the author only. This report
is subject to revision upon collection of additional data.

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, com-
pleteness, 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 con-
tractor 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.

DECLASSIFIED

D I S T R I B U T I O N

1. TW Ambrose	24. RW Reid
2. ER Astley	25. OC Schroeder
3. RS Bell	26. CA Priode
4. PA Carlson	27. HG Spencer
5. MA Clinton	28. JT Stringer
6. RF Corlett	29. GE Wade
7. RE Dunn	30. WK Woods
8. WJ Ferguson	31. 300 Area Files
9. NF Fifer	32. Records Center
10. GC Fullmer	
11. SM Graves	
12. OH Greager	
13. RS Hammond	
14. HW Heacock	
15. KL Hladek	
16. DL Hovorka	
17. RT Jessen	
18. LE Kusler	
19. LW Lang	
20. WN Mobley	
21. CA Munro	
22. R Nilson	
23. GF Owsley	

DECLASSIFIED

April 24, 1964

C-REACTOR OVERBORE TEST FACILITY REVIEWINTRODUCTION

In 1961, large-size, smooth-bore, Zircaloy process tubes were installed in C-Reactor graphite channels that had been enlarged to 2.275 inches. These tubes were installed to provide a test and demonstration facility for the concept of overboring as a means of securing significant improvement in the production capability of the reactors. After two years of facility operation, it is now appropriate to consider the extent to which original objectives have been achieved, to re-examine the original objectives, and to consider the best future use of this unique facility. Reference 1 considered these points with primary emphasis on the latter. This report presents the general results of such a review and re-examination in more detail.

SUMMARY AND CONCLUSIONS

The overbore process tubes were installed in C Reactor to demonstrate the feasibility of overboring, to confirm conversion ratio and fuel design predictions, to evaluate overbore equipment, and to obtain a measure of fuel performance. These objectives have been reasonably achieved with the exception of a fuel performance demonstration. Although nearly 9500 fuel elements have been irradiated successfully in the overbore facility at conditions exceeding those normally achieved by current production fuels, it is still not possible to predict with certainty the normal level of fuel performance in relation to the performance of current production fuels. Failures have been experienced in 11 of the 9500 fuel elements irradiated to date which, taken at face value, indicates less than adequate behavior. However, each of these failures can be associated with abnormal and atypical conditions to the extent that to consider them as representing normal overbore fuel performance is highly questionable. No failure mechanisms have been experienced which indicate limitations peculiar to the overbore concept. The examination of irradiated overbore fuel elements revealed no unusual irradiation effects. If the fuel performance for the nonrepresentative conditions is excluded from consideration, the remaining experience indicates that a reactor overbore program could proceed with a high degree of confidence in favorable results. However, additional irradiation experience, perhaps coupled with a run-to-rupture demonstration, is needed to satisfy the original objective of establishing, with a high degree of certainty, a fuel performance index for overbore fuel.

The need to continue to use the overbore facility for its original purpose depends upon the potential for future overboring of a reactor for plutonium production. This concept has not been favorably considered by the Atomic Energy Commission. Therefore, in the current and projected production climate, the need to fully demonstrate the overbore technology for plutonium production may be somewhat less pressing. Assuming the potential for future overboring for plutonium production is in fact remote, the facility should be used in a way which is more consistent with future needs or which offers the least interference with normal production activities.

DECLASSIFIED

In examining these options, it is noted that the investigation of alternate reactor uses is currently one of the primary Department objectives. Therefore, it is recommended that test programs be conducted in the facility to provide a production technology base for isotope production, for which an overbore lattice is uniquely suited. At present, the two most promising future uses appear to be in the production of polonium and in the production of higher-mass isotopes from the burning of plutonium. The production of polonium in the overbore facility would be a good way to preserve the channels, produce plutonium, and test the concept, simultaneously. A plutonium burning scheme may develop from present studies which is better suited for an overbore flux spectrum and which warrants in-reactor testing. Since these studies have not progressed much beyond the concept stage, it is recommended that the overbore facility be maintained in its current operating basis for at least an additional ten months to provide time for these diversification schemes to materialize. If a need for the facility does not develop as expected during this period, consideration will be given at this time to returning the channels to normal production service.

BACKGROUND

A development program to determine the technical feasibility of overboring the graphite tube channels was begun in late-1959. Six channels in DR Reactor and 1 1/2 channels in F Reactor were successfully overbored 0.200 inches. The next step in the program was to determine the feasibility of enlarging the channels further; requiring, in addition, enlargement of the penetrations through cast iron shields and shield rings or donuts. Early in 1961, twenty-two tube channels in 105-C were enlarged 0.550 inches and equipped with large-size, Zircaloy-2 process tubes, nozzles and gunbarrels for use with overbore fuel elements. The results of this work were favorable and it was concluded that reactor channel overboring was technically and economically feasible.^[2] Therefore, the overbore facilities at 105-C were expanded to 62 tubes, late in 1961, to permit pilot testing for the complete conversion of the reactor to enlarged fuel elements.^[3,4]

Concurrently, a laboratory testing program was performed to investigate the physics characteristics of the overbore lattice, the hydraulic characteristics of the overbore equipment, the normal heat transfer characteristics of the overbore fuel elements, and the hydraulic and heat transfer characteristics of the overbore equipment during accidental flow-loss and power-surge conditions. The flow tests confirmed the computed channel hydraulic characteristics and fuel design.^[5] Data were obtained in the heat transfer experiments which served as a basis for establishing flow monitoring procedures.^[6] The material buckling of the overbored lattice was determined for both natural and enriched uranium to assist in determining reactor loadings.^[7,8] Safety rod strengths were measured and the reactivity effect of water loss and core flooding determined. The data obtained in these tests were favorable, demonstrating the technical feasibility and safety of the overbore concept with respect to reactor operations. In addition, a hazards review was issued which concluded that the over-all nuclear safety of the 8 3/8-inch lattice reactors would be materially improved by the overbore modification.^[8]

Of the 62 overbore tubes currently installed in C Reactor, 44 are in a block near the center of the reactor, two are in the lower part of the reactor, and the remaining 16 are located in the reactor fringes. Since the overbore fuel and tubes are larger

DECLASSIFIED

with less surrounding graphite, the effective lattice is considerably changed from the normal C lattice. These larger tubes rob neutrons from the surrounding lattices and operate at higher powers than the regular C-Reactor fuel. To compensate, the central zone tubes are charged with 19 pieces to keep the tube powers consistent with the others of the reactor. The fringe tubes have a normal-length charge, but do generate some of the maximum tube powers in the reactor. The 44-tube block was designed primarily to give conversion ratio data and fuel testing space. Since the block does rob neutrons, special enrichment around the block is required. The tube powers can be controlled by short charging but specific powers cannot be reduced in this manner. Thus, the specific powers have been higher than would be typical in a fully overbored reactor, this is particularly true of those charges on the two outer rows of the block. The block thus provides considerable test space and the opportunity to operate the test fuel at specific powers higher than those to be expected in a completely overbored reactor. The test results must, of course, be interpreted in light of these accelerated test conditions.

OBJECTIVES OF C-OVERBORE PROGRAM

The objectives of the C-overbore program were as follows:

1. to demonstrate the technical and economic feasibility of overboring, ✓
2. to evaluate overbore reactor equipment,
3. to obtain engineering fuel design data, ✓
4. to obtain an index of fuel performance to be expected in the overbored reactor, and ✓
5. to obtain conversion ratio and product quality information applicable to the future modified reactor conditions. ✓

EXTENT TO WHICH OBJECTIVES ACHIEVED:

1. Demonstration of Feasibility

The C-overbore experience fully demonstrated that large-scale overboring of the Hanford reactors is completely feasible.^[9] Considerable depth in the development of necessary equipment and modification techniques was achieved. Problems which would be faced in a full-reactor program were identified. Significant achievements were the development of equipment which enlarges the inner donut, the gunbarrel penetration in the thermal shield, and the first graphite bar in one operation. Graphite machining tools were developed which are capable of overboring a process channel in 3.2 minutes. Special welding equipment to automatically weld a new centering flange onto the biological shield was developed.

Minor problems identified during the program were the need for a more efficient means of disposing of radioactive gunbarrel tips, and the need for personnel training to achieve a high degree of efficiency in performing several operations simultaneously.

DECLASSIFIED

The success of the channel enlargement work at C Reactor erased all doubts concerning the technical and economic feasibility of reactor overboring. This objective of the C-Overbore Program was fully realized.

2. Equipment Development

The decision to install an overbore test and demonstration facility provided the unique opportunity to test new process tube assembly designs under actual operating conditions. Increased strength and reliability and reduction of maintenance were the basic criteria for the new equipment. Basically, two sets of inlet and outlet equipment were designed and procured for installation on the reactor test facility. Some of the more outstanding features of this equipment were as follows: [10]

- a. The use of wrought alloy for the inlet nozzles allows integral lugs, thus, eliminating potential problems with snap ring failures.
- b. The use of four lugs to retain the caps increases the strength and reliability.
- c. Gas tubes were used on both the inlet and outlet assemblies to move the gas seals outside the crossheaders for ease of maintenance.
- d. A new type flow meter was tested.
- e. Welded collars in addition to Van Stone flanges were tested as a means of attaching the Zircaloy process tubes to the nozzles.
- f. Soft aluminum seals were used for the static gas seals in both assemblies.
- g. The cast rear nozzles of each assembly provided an integral housing for protecting the temperature sensing elements.

In general, the process tube assemblies have performed satisfactorily. A few minor problems appeared as the equipment was used; however, most of these were readily solved. For full reactor conversion, the need remains to develop charging machines for the overbore self-supported fuel elements. Attempts to machine-charge the overbore fuel elements have not been successful. The first machine used was modified, regular C-Reactor equipment. Problems with alignment of the fuel elements while passing into the nozzle caused damage to the fuel supports. Two fuel ruptures were sustained because of this damage. Displacement-discharging was unsuccessful, primarily because of the high forces required to move the heavy charge. In this case, damage to fuel supports was evident despite proper alignment at the nozzle. A second machine of different design was tested and found to cause excessive damage to the fuel elements. This machine was not used to charge elements for irradiation. De-emphasis of the overbore program in 1963 essentially stopped further charging machine development for overbore fuel elements. The C-overbore fuel elements have been hand-charged since July 1962. Development of self-supported charging machines was continued, however, in support of the K-Reactor retubing program. The satisfactory development of a charging machine for K self-supported fuel elements indicates that adequate designs for overbore fuel may be achieved with additional development effort.

DECLASSIFIED

A potentially serious problem associated with the discharge of severe ruptures from Zircaloy tubes with rear welded collars was indicated. Thus, although the welded collar provides a joint nearly as strong as the Zircaloy tube, the rupture discharge problems experienced in the operation of the test facility would result in their being unsatisfactory for full-scale application. The less costly Van Stone flange performed well in the overbore facility and is the joint selected for the K-Reactor conversion to Zircaloy tubes.

3. Fuel Element Design

Data obtained in the operation of the overbore test facility confirmed heat transfer calculations and provided valuable data on support design. Information was obtained upon which to base future overbore fuel designs to provide for optimization of fuel operating characteristics. This objective was fully realized.

4. Fuel Element Performance

While considerable experience with overbore fuel elements has been obtained, it is still not possible to project with certainty just what the normal level of fuel performance is in relation to the performance of current standard production fuel elements. Eleven failures have occurred out of nearly 9500 fuel elements irradiated which, taken at face value, indicates a lower level of performance than that experienced with normal fuel. But, each of these failures can be associated with abnormal or atypical conditions to the extent that to consider them as representing normal overbore performance is highly questionable.

A history of overbore fuel failures is shown in Table I. The first failure, which occurred in January 1962, was attributed to charging machine damage. Considering the great amount of charging machine damage being sustained at this time (some support bridges were completely sheared off), it is perhaps remarkable that more fuel failures did not result from this cause. Certainly the fact that the overbore fuel elements operate with lower surface heat fluxes than normal fuel, because of their increased heat transfer surface area, would lead one to conclude that overbore fuel elements would be more resistant to failure by this mechanism than normal-size fuel. A second fuel element failed by this mechanism in September 1962.

On April 16, 1962, examination of the fuel charge in overbore tube 3062-C revealed three split failures and three "worm tracked" elements (depressions in the aluminum can giving the impression that the uranium beneath is split and the can is approaching failure). These failures occurred approximately 10 days after one period of flux cycling and during a second such cycle at C Reactor. An increase of outlet temperatures above normal, extending over a period of a few hours, occurred in the 44-tube, central zone, overbore block. Maximum specific powers of 150 kw/ft were estimated to have occurred for a short period of time in the maximum-powered overbore tube and 135 kw/ft in the failure tube. Normal maximum specific power in the 19-piece test loadings is 120 kw/ft. These fuel failures were a direct result of the high specific powers and of the exaggerated flux cycling of the high-exposure material. C Reactor, fully-overbored, would

DECLASSIFIED

TABLE I

OVERBORE FUEL FAILURE SUMMARY

<u>Failure Date</u>	<u>Tube Number</u>	<u>Fuel Column Length</u>	<u>Column Exposure</u>	<u>Column Position No. of Failures</u>	<u>Tube Power</u>	<u>Average Column Specific Power</u>	<u>Failure Mechanism</u>	<u>Cause</u>
1-16-62	4463-C	32	631 Mwd/t	4	1475 kw	60 kw/ft	Groove corrosion penetration of jacket.	Charging machine damage.
4-16-62	3062-C	19	676 Mwd/t	12 14 15	1439 kw	102 kw/ft	Core split longitudinally.	Extreme flux cycling.
8-29-62	3162-C	19	640 Mwd/t	16	1243 kw	88 kw/ft	Core split transversely.	Unknown, but dingot uranium.
9-03-62	1494-C	32	714 Mwd/t	1	1201 kw	51 kw/ft	Groove corrosion penetration of jacket.	Charging machine damage.
9-06-62	2969-C	19	401 Mwd/t	16	1265 kw	90 kw/ft	Core split.	Unknown, but dingot uranium.
8-25-63	3062-C	19	490 Mwd/t	12	1266 kw	90 kw/ft	Water entry at end cap.	Defective core-to-clad bonding.
10-29-63	1464-C	19	269 Mwd/t	Unknown	1352 kw	96 kw/ft	Water entry at end cap.	Defective core-to-clad bonding.
12-30-63	2969-C	19	185 Mwd/t	Unknown	1427 kw	100 kw/ft	Water entry at end cap.	Defective core-to-clad bonding.
1-18-64	3366-C	19	315 Mwd/t	Unknown	1475 kw	105 kw/ft	Water entry at end cap.	Defective core-to-clad bonding.

PA Carlson:go

DECLASSIFIED

generate about 70 kw/ft average specific powers and maximum specific powers of about 100 kw/ft. Performance of the overbore fuel at the normal maximum test conditions of 120 kw/ft has been good. Failure in the 135 to 150 kw/ft range perhaps establishes a rough upper limit to overbore fuel operation—a limit substantially above the powers to be expected in the fully-overbored reactor.

These were followed by two split failures, one each in August and September 1962. Common features of these failures were that each was split transversely and had been fabricated of dingot uranium. The irradiation behavior of dingot fuel elements has, in general, been poor. The rupture rate experienced with dingot metal has been about a factor of three worse than ingot performance.^[11] It would not seem, therefore, that these two failures are indications of overbore fuel element performance at normal conditions.

And finally, the four most recent overbore failures have been the end cap type. Each of these failures was characterized by a defective core-to-cladding bond between the female end cap and the fuel core.

Examination of fuel elements irradiated in the same tests with these failures revealed extensive cap-to-core unbonded areas, and that lead, presumably carried over in the canning bath, was present in the unbonded areas. These fuel elements were further characterized by the fact that the can wall between the cap and core had been stretched. An examination of unirradiated pieces also showed these manufacturing defects. It is believed, therefore, that these four overbore failures resulted from the lack of bonding at the end cap.

It is significant that each group of fuel element failures is attributable to conditions nonrepresentative of normal operation. Therefore, to consider the overbore failures as representing normal overbore performance is highly questionable. It is significant that no fuel failure mechanisms have been experienced which are indicative of limitations peculiar to overbore fuel. Also, examinations of irradiated fuel elements have revealed no unusual irradiation effects. If the fuel performance for these nonrepresentative conditions is excluded from consideration, the remaining experience indicates that a reactor overbore program could proceed with a high degree of confidence in achieving favorable results. However, additional irradiation experience is needed to satisfy the original objective of establishing a fuel performance index with a high degree of certainty. The original program of overbore fuel testing included a run-to-rupture test to aid in determining this fuel performance index. This part of the program was dropped when it was decided that the loss of reactor production which would result from the rupture test was not justified in view of the unfavorable response of the Commission to full reactor conversion to an overbored status. It would be difficult to obtain an index by irradiating fuel elements in the overbore facility to normal exposures, because of the relatively small number of process tubes. Thus, unless the run-to-rupture test were rescheduled, several years of operation of the overbore facility would be required to develop a statistically-significant quality index. Run-to-rupture tests with normal-sized fuel elements indicated that use of the self-supported fuel concept would improve hot spot performance relative to normal fuel elements. Experience being accumulated at the K Reactors appears to be confirming this preliminary result.

DECLASSIFIED

The operating characteristics of the overbore fuel elements differ from those of normal-sized self-supported fuel in that the stress levels are higher, which could indicate a possible split failure problem, and normal jacket heat fluxes and surface temperatures are lower because of the greater heat transfer surface area. Adequate resistance to split failure has been demonstrated by successful routine irradiation of the overbore fuel elements at specific powers up to 120 kw/ft, which are 20 per cent higher than the maximum specific power in a fully-overbored C Reactor. Improved performance with respect to jacket corrosion failures would be expected due to the lower surface heat fluxes. The relatively few failures which were experienced during the period when overbore fuel with damaged supports was irradiated is encouraging in this respect. Thus, although an overbore fuel element quality index has not been established with certainty, enough information has been developed to provide reasonable confidence that overbore fuel performance would be adequate for the economic operation of an overbored reactor.

5. Product Yield

Since the major incentive for overboring was to increase the yield of plutonium, it was important that an experimental determination be made of the plutonium yield in the overbore geometry. Eight central tubes of the 44-tube block, 3064 to 3067 and 3164 to 3167, were chosen to make these measurements. The fuel in these innermost tubes should "see" a neutron spectrum most like that of a fully-overbored reactor.

In addition to determining the yield of plutonium isotopes in the overbore geometry, measurements were also made of other isotopes such as Np-237, Am-241 and Cm-242. Today, in retrospect, these additional measurements serve a useful purpose in assessing the value of overboring beyond that originally planned.

Only natural uranium fuel was used in the test block. To be fully self-supporting, an overbored reactor would need to be slightly enriched (0.815 wt % U-235). Thus, the test results are not completely representative of a fully-loaded overbore reactor. However, the differences should be small, and the test results provide their chief value in correlating calculational methods and qualitatively indicating the gains which can be made by overboring.

The tubes in which fuel was specially discharged for isotopic analysis are listed in Table II. The test fuel was irradiated to two different exposures; one near half-goal, the other near goal. The tube powers, and consequently exposure, were determined from temperature and coolant flow measurements. Several temperature maps were taken each month. Exposures were determined by routine production scheduling calculations and checked by independent calculations from daily reports. The exposure values determined by the two calculations differed by less than 2 per cent.

TABLE II
C-OVERBORE FUEL DATA

<u>Tube Numbers</u>	<u>Exposure</u>	<u>Date Discharged</u>
3064 - 3067	382 Mwd/t	8-10-62
3164 - 3167	408 Mwd/t	8-10-62
3064 - 3067	714 Mwd/t	5-06-62
3164 - 3167	790 Mwd/t	7-6-62

DECLASSIFIED

Each process tube contained 19 fuel elements; each overbore element weighed 18.47 pounds (U). Each batch of 76 fuel elements was dissolved separately in the Redox Process C-2 dissolver and sampled according to standard procedures. A 20-ml sample was used for the isotopic analyses. Redox Laboratory Operation made the chemical analyses. The mass spectrometer analyses were made by the Control Operation, Weapons Manufacturing Operation, CPD. The results of the analyses were reported in References 12 and 13.

a. Plutonium Yield

The g/t of plutonium is plotted in Figure 1 as a function of exposure. The data agree well with the theoretical values. Also shown, is the plutonium yield for normal-size fuel (CIIN) in C Reactor.^[14] It is seen that the overbore yield is significantly greater—as predicted. The approximate increase in plutonium is 10 per cent at the lower exposure points and 16 per cent at the higher exposure points. However, the 714 Mwd/t datum point appears too high; the other three points fall on a smooth curve. If the 714 Mwd/t datum point is ignored, the gain at the higher exposure is 11.5 per cent.

The percentage yields of Pu-240 and Pu-241 are shown in Figures 2 and 3. The Pu-240 fraction agrees, generally, well with the theoretical curve (the 382 Mwd/t datum point seems high). The Pu-240 differs little from that in the normal CIIN fuel geometry (curve also shown). This indicates that the combined effects of higher neutron temperature (which should exist in the blacker overbore fuel) and more epithermal flux (due to the higher fuel-to-moderator ratio) are largely zero in altering the Pu-240 buildup.

Theoretically, due to the greater epithermal flux in the overbore lattice, the Pu-241 yield should be greater in the overbore lattice than in the normal CIIN-fueled lattice. The experimental yields of Pu-241 shown in Figure 3 do not, however, appear to be as large as the theory predicts. The yields are, in general, higher than those in normal-size fuel, although some of the data are of questionable value.

One of the advantages of the overbore facility should be the harder neutron spectrum, which should be useful in producing higher isotopes. The first measure of this ability should be the Pu-241 buildup. This isotope is formed from Pu-240 (which has a prominent resonance at 1 ev), and its formation should be sensitive to the spectrum. It is disappointing that the Pu-241 data are not better; about all that one can say from the data in Figure 3 is that there is an indication that the Pu-241 formation is higher in the overbore fuel. Fortunately, the fact that the amount of other higher isotopes was also determined in the analyses, sheds additional light on the usefulness of an overbored lattice in the production of higher isotopes (see section on Am-241 and Cm-242).

b. Neptunium Yield

The neptunium yield from the overbore fuel is shown in Figure 4. Here, is truly a previously-unemphasized advantage of overboring. The neptunium

DECLASSIFIED

FIGURE 2.

Pu-240 YIELD IN OPERABLE FUEL

DECLASSIFIED

FUEL EXPOSURE, Mwd/t

yield is up nearly 40 per cent (the curve shown is the theoretical neptunium yield for a small reactor). The neptunium yield would be further increased in recycled fuel due to the advantageous flux spectrum with regard to the U-236 cross section. The gain shown in Figure 4, for virgin uranium, is principally due to an increase in the $n,2n$ reaction in U-238 which leads to Np-237.

c. Higher Isotope Yields

The measured yields of Am-241 and Cm-242 are shown in Figures 5 and 6. Also shown, are similar data from natural uranium fuel elements of the conventional size (H and K Reactor). The Am-241 data are not highly accurate since the analyses were made at varying times up to a year after the discharge of the fuel, and in some cases 90 per cent of the Am-241 measured was formed from Pu-241 decay during the cooling and storage time. To give meaningful information (since cooling times varied), the Am-241 data were corrected back to time of discharge. It is in making this correction that most of the uncertainty enters since the correction involves the Pu-241 data which are neither very accurate nor consistent. Nevertheless, the corrected Am-241 yield from the overbore tests is definitely higher than that from the normal-size fuel elements. This corroborates the rather poor Pu-241 data that the neutron spectrum in the overbore lattice will considerably enhance the production of higher isotopes. The curium data, shown in Figure 6, also show an advantage to the overbore fuel, but the data are quite scattered. The Cm-242 data did not need to be corrected since there is no Cm-242 formed after the fuel is discharged.

d. Summary of Product Yields

The product yield tests are considered complete for the purposes for which they were intended. The expected high plutonium yield was verified. The increase in Np-237 yield is well understood in terms of current production schemes. Better data on the Pu-241, Am-241, and Cm-242 isotopes would have been desirable, but there is little to be gained in further measurements of these isotopes in overbore, natural uranium fuel irradiations since the prospect for an overbore reactor appears slight. However, further isotope determinations in fuel types more likely of future implementation would be very valuable.

DECLASSIFIED

CM-242 YIELD, $\mu\text{g/t}$

100

200

300

FIGURE 4
CM-242 YIELD IN OVERBORE FUEL

FUEL EXPOSURE, Mwd/t

DECLASSIFIED

NEED TO CONTINUE CURRENT PROGRAM

It is concluded that the original objectives of the overbore program were achieved, with the exception that a fuel performance index has not been established with certainty. A large amount of fuel performance data has been obtained, however, which indicates that the performance of the overbore fuel design should equal that of their smaller-sized counterparts, whose irradiation performance has been statistically proven to be superior to that of ribbed-tube fuel designs. Therefore, the lack of an established performance index should not limit consideration of reactor overboring for plutonium production. It would be advantageous to continue the current program in the overbore facility, however, if approval of overboring for plutonium production was considered likely. It is noted that the concept has not been favorably accepted by the Atomic Energy Commission either on the grounds of increased plutonium production or as a means of decreasing costs for a fixed level of plutonium production. Therefore, in the current and projected production climates, the need to fully demonstrate the overbore technology for plutonium production may be less pressing. Assuming the potential for overboring for plutonium production is in fact remote, the facility should be used in a way which is more consistent with future needs or which offers the least interference with normal production activities. In examining these options, it is noted that the investigation of alternate reactor uses is a prime objective of the Department. Therefore, it is recommended that test programs be conducted in the facility to provide a production base for isotope production for which an overbore lattice is uniquely suited. Possible future uses of the overbore facility in support of diversification studies is discussed below.

POSSIBLE FUTURE USES OF FACILITY

Beyond the completion of the current program, the overbored tubes offer many advantages for future study. The overbore geometry exhibits two major deviations from the normal reactor lattices: (1) the much greater volume available for fuel and target element irradiation, and (2) a harder flux spectrum resulting from a higher fuel-to-moderator ratio in the lattice. Examining these in greater detail, several potential uses are noted to be compatible with these unique characteristics and are discussed below.

1. Polonium Production

Increasing polonium production capability has been studied and one of the irradiation techniques which appears attractive is to overbore the present process channels and insert aluminum-jacketed bismuth in the volume made available by removal of graphite.^[15] Since bismuth has such a low neutron capture cross section, the polonium production is regulated by tonnage of bismuth under irradiation and the neutron flux. Consequently, the overbored channel has the advantage of affording the space for large quantities of bismuth at a small enrichment increment. Existing overbore channels could be used for demonstrating this concept, assuming interest by the AEC in a proposal submitted by IPD, CPD, and NRD.^[16] It is estimated that one gram of polonium could be produced per tube on a yearly irradiation schedule without loss of plutonium production. (The loss in plutonium production is estimated at 100 grams for each gram of polonium produced when bismuth displaces uranium.) Polonium could also be produced by replacing the solid dummies in the downstream patterns of the presently short-charged overbore tubes with bismuth elements.

DECLASSIFIED

Potentially, a portion of the facility could be used to support research and development for separating polonium and bismuth at Hanford. Included in this concept are tests to evaluate the feasibility of recovering bismuth trioxide, after separation of the polonium, for reirradiation. Currently, bismuth is not recovered because of the low quantities of material processed; however, large quantity production would most likely require re-use. In-reactor loop irradiation of bismuth trioxide with polonium separation at the reactor has also been proposed by CPD and NRD, but the associated development problems seem particularly complex at this stage of development knowledge. N Reactor, however, is examining this possibility in considerable detail.

2. Tritium Production

The greater volume available in an overbore channel lends itself to the concept of an enriched driver element surrounding a target element. This arrangement permits more flexibility than the usual striped loading or complete separation of the enrichment and target material. If the climate towards tritium production were to moderate, an overbored E-N test could serve a useful purpose as there are definite production gains to be achieved in such a loading.

3. High-Mass Isotope Production

As pointed out in the section on product yield, the harder neutron spectrum in an overbored facility is useful in converting plutonium to higher-mass isotopes. Many of these isotopes are becoming useful, either in themselves (Cm-242) or as targets to produce other useful isotopes (Am-241). A plutonium fuel test could either be made up of fuel alone or a fuel and target concept. Currently, studies and initial development work have been started to explore the use of plutonium-bearing elements in the Hanford production reactors, and overbore will be investigated in considerable detail in this regard.

The majority of the tubes of the block facility would have to be used to provide data on plutonium burning schemes, since the proper neutron flux spectrum is important in these studies. Accurate analyses of all isotopes of interest (Pu-240, Pu-241, Am-241, Cm-242 and Cm-244) would be required. A study of the effects of varying Pu-240, initially present in the fuel, will be of interest and a rather extended testing program can be envisioned.

4. Thorium or Depleted Uranium Loadings

Thoria or thorium targets cannot be practically loaded in the same channel as the driver element because of the different discharge cycles and the U-232 contaminant produced by unmoderated neutrons from the enriched driver elements. In general, the production of U-233 is not compatible with the overbore lattice because the associated harder flux increases the U-232 contaminant. Enriched-depleted uranium loadings have also been considered, but the spectrum would not be appropriate for producing high-240 content plutonium.

DECLASSIFIED

5. Test Facility for Power Recovery Fuels

The studies of power recovery from a small reactor have indicated the need for an oxide element compatible with high exposures. Further, this oxide element would be maintained in a horizontal position as contrasted to the major experience of oxide elements in the vertical position. Preliminary testing of this concept could be performed in the overbore geometry with a small degree of dimensional scaling. The long-time periods required for demonstration of the necessarily high goal exposures would imply that development work should be commenced before long, if real consideration is being given to reactor conversion.

6. Other Uses

Other, more remote uses are also possible. Some of these may be: 1) flux amplifiers for producing high specific activity isotopes, 2) high power irradiations, 3) exotic loops where large-diameter irradiation space is needed, etc. No definite programs exist now for these uses.

PA Carlson

Senior Engineer, Reactor Engineering
Process and Reactor Development
Research and Engineering Section, IPD

R Nilson

Supervisor, Reactor Physics
Process and Reactor Development
Research and Engineering Section, IPD

PA Carlson/R Nilson:go

DECLASSIFIED

B I B L I O G R A P H Y

- [1] Ambrose, T. W. C-Overbore Facility - Operation Plan. February 11, 1964. (CONFIDENTIAL UNDOCUMENTED)
- [2] Munro, C. A. Final Report - Production Test IP-360-AK, Overboring Demonstration Cast Iron and Graphite Bore Enlargement 105-C, HW-71711. March 1, 1962. (CONFIDENTIAL)
- [3] Van Wormer, F. W. Technical Bases and Criteria Expansion of Overbore Test Facilities C-Reactor, HW-70648. May 22, 1961. (SECRET)
- [4] Van Wormer, F. W. Production Test IP-431-A, Expansion of Overbore Test Facilities, C Reactor, HW-70702. August 11, 1961. (SECRET)
- [5] Calkin, J. F. Hydraulic Pressure Drop Data for C Overbore Tubes and Fuel Elements, HW-68784. March 9, 1961. (CONFIDENTIAL)
- [6] Waters, E. D., and M. R. Kreiter. Results of Laboratory Heat Transfer Experiments for C-Reactor Overbore Fuel Channels, HW-71075. November 10, 1961. (SECRET)
- [7] Johnson, D. L. Overbore Program Exponential Experiments, HW-78320. July 11, 1963. (CONFIDENTIAL UNDOCUMENTED)
- [8] Johnson, D. L. Material Buckling Measurements of a Supercell Using Enriched and Natural Fuel, HW-79037. September 23, 1963. (CONFIDENTIAL UNDOCUMENTED)
- [9] Personal communication, C. A. Munro, April 5, 1964.
- [10] Fifer, N. F. Development of Overbore Process Tube Equipment, HW-71420. To be issued.
- [11] Reid, R. W. Rupture and Water Leak Memorandum - April 1962, HW-73736. May 22, 1962. (SECRET)
- [12] Ringle, R. P. Analysis of Two Groups of C-Overbore 0.5 Goal Material, HW-78501. August 1, 1963. (SECRET)
- [13] Ringle, R. P. Analysis of Two Groups of C-Overbore 1.0 Goal Material, HW-78499. August 1, 1963. (SECRET)
- [14] Vaughn, A. D. IPD Plutonium Tables, HW-50300-B Rev. March 1, 1961. (SECRET)
- [15] Lang, L. W., et al. HAPO Isotope Program -- Po-210 Production, HW-78525. August 7, 1963. (SECRET)
- [16] Tomlinson, R. E., et al. Alternative Production Methods for Polonium-210, HW-80867. February 14, 1964. (CONFIDENTIAL)

DECLASSIFIED

**DATE
FILMED**

6/22/94

END