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

DUN-2994-DEL

SERIES AND COPY NO.

A-30

DATE

August 20, 1967

TITLE

K REACTOR GRAPHITE TEMPERATURE
ECONOMICS RELATIVE TO HELIUM LOSS RATES

AUTHOR

L. J. Newell

ISSUING FILE

CIRCULATING COPY
RECEIVED 700 AREA

SEP 12 1967

RETURN TO
DOUGLAS UNIT NUCLEAR, INC.

DOCUMENT NUMBER

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE PROVISIONS, 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.

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE PROVISIONS, 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.

THIS DOCUMENT MUST NOT BE LEFT UNATTENDED OR WHERE AN UNAUTHORIZED PERSON MAY HAVE ACCESS TO IT. WHEN IN YOUR POSSESSION, IT MUST BE STORED IN AN APPROVED LOCKED REPOSITORY WITHIN AN APPROVED GUARDED AREA. IT IS YOUR RESPONSIBILITY TO KEEP THIS DOCUMENT WITHIN THE LIMITS OF THIS PROJECT AND FROM ANY UNAUTHORIZED PERSON. IF ADDITIONAL COPIES ARE REQUIRED, OBTAIN THEM FROM THE ISSUING FILE. ALL PERSONS RECEIVING THIS DOCUMENT ARE REQUESTED TO SIGN IN THE RECORD COPY PROVIDED BELOW.

ROUTE	PAYROLL NO.	LOCATION	FILES ROUTE DATE	SIGNATURE AND DATE
DUN Record				
53456	14-1-N	4-18-67	J. P. X	11-21-67
53812	14-1-N	4-18-67		

RECORD COPY

DUN RECORDS DISPOSITION

Indefinite Retention

Destruction Date

Authority

Until facility is abandoned
13-5.2

Classification reviewed for
but left unchanged
by *[signature]*

Date *23-10-63*

**DECLASSIFIED
WITH DELETIONS**

MASTER

DECLASSIFIED

-1-

DUN-2994

DEL

Hanford Code C-65

This document classified by:

PA Alarson

This document consists of
18 pages. 30 of

**DECLASSIFIED
WITH DELETIONS**

Classification Cancelled and Changed To

K REACTOR GRAPHITE TEMPERATURE
ECONOMICS RELATIVE TO HELIUM LOSS RATES

By Authority of CG-NMP-1
DS Lewis 5-10-94
By DA Krukowski 5-10-94
Verified By PA Eick 5-10-94

L. J. Newell

DOUGLAS UNITED NUCLEAR, INC.
RICHLAND, WASHINGTON

NOTICE

THIS REPORT WAS PREPARED FOR USE WITHIN DOUGLAS UNITED NUCLEAR, INC. IN THE COURSE OF WORK UNDER ATOMIC ENERGY COMMISSION CONTRACT AEC-1157, AND ANY VIEWS OR OPINIONS EXPRESSED IN THE REPORT ARE 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, COMPLETENESS, OR USEFULNESS OF THE INFORMATION CONTAINED IN THIS REPORT, OR THE USE OF ANY INFORMATION, APPARATUS, METHOD, OR PROCESS DISCLOSED IN THE 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.

DECLASSIFIED

DISTRIBUTION

1. T. W. Ambrose	16. H. W. Heacock
2. D. H. Bangerter	17. K. L. Hladek
3. R. S. Bell	18. R. T. Jessen
4. P. A. Carlson	19. C. W. Kuhlman
5. T. M. Clement	20. L. C. Lessor
6. R. G. Clough	21. R. V. Myers
7. P. J. Cooke	22. L. J. Newell
8. R. E. Dunn	23. G. F. Owsley
9. K. R. Ellison	24. R. W. Reid
10. M. L. Faught	25. O. C. Schroeder
11. G. C. Fullmer	26. A. P. Vinther
12. R. E. Hall	27. R. K. Wahlen
13. R. S. Hammond	28. S. A. Wood
14. J. P. Hamric	29. DUN File
15. A. K. Hardin	30. DUN Record

| DECLASSIFIED

DECLASSIFIED

-3-

DUN-2994

DEL

K REACTOR GRAPHITE TEMPERATURE
ECONOMICS RELATIVE TO HELIUM LOSS RATES

INTRODUCTION

The purpose of this report is to present the results obtained from a study to determine the most economic K Reactor graphite temperature for assumed helium loss rates and the economic incentives for reducing the helium gas losses at these reactors. Similar studies ^{1,2} have been completed for the B, C, and D Reactors.

In order to obtain a prescribed length of service from the Hanford reactors, a maximum graphite temperature limit is specified. Control of the graphite temperature within the limit is primarily accomplished by varying the concentration of helium present in the reactor gas atmosphere. This introduces an economic parameter of significant importance because of gas losses suffered by the reactors and associated helium costs.

The graphite temperatures referred to in this report are the maximum side-to-side stringer temperatures, which are directly proportional to the average graphite moderator temperature. Based on operating data, a base case maximum side-to-side graphite stringer temperature of 720 C is chosen as typical of those encountered in a K Reactor natural uranium loading (6 percent Pu-240) at the current administrative power level limit.

This temperature is used as a convenient base for comparing the economic effects of changes in graphite temperature. It should be noted that the difference between the base and other case values is the significant number. Thus, an optimum graphite temperature of 670 C means that the economic optimum is 50 C below current temperatures with the reactor operating with a natural uranium loading.

SUMMARY

A substantial economic incentive (Figure 1) to lower the helium gas losses at the K Reactors is indicated by this study.

For example, a reduction in helium gas losses by 75 percent results in an increase in annual net return of about \$140,000 per K Reactor with a natural uranium loading (6 percent Pu-240).

At current helium gas leak rates, an optimum graphite temperature of 670 C is indicated. Operation at this temperature instead of 720 C would result in a reactor net return increase of \$230/calendar day. For the 75 percent gas leak rate reduction case, the maximum return occurs at a graphite temperature of 620 C.

1. Scott, J. H., "Economic Consequences of Elevated Graphite Temperature - B and D Reactors," DUN-612. March 2, 1966. (Secret)
2. Newell, L. J., "Economic Evaluation of Optimum Graphite Moderator Temperature - C Reactor," DUN-1371, August 8, 1966. (Secret)

The adjusted net return* and incremental net return (economic incentive) for a K Reactor is summarized below for the cases studied.

Helium Losses	Current	Current	25% of Current	No. Losses
Graphite Temperature - °C	720 (Base)	670	620	580
Adjusted Net Return-\$/Cal. day	48,790	49,020	49,408	49,600
Incremental Net Return \$/Cal. day compared to base	0	230	618	810
Incremental Net Return \$/Cal. day compared to current with 670 C temperatures	---	0	388	580

Because of recent interest in the production of high Pu-240 plutonium and the possibility of a relaxation in the administrative power level restriction, these changes were evaluated by additional computer runs made following completion of the original analysis.

The results of these runs were as follows:

- 1) Reactor operation with K5N fuel discharge exposures to produce 12 percent Pu-240 plutonium offers no economic incentive (Figure 2) to reduce graphite temperatures from the standpoint of increased net return. However, there is still a substantial economic incentive to minimize current helium gas leak rates.
- 2) With power level restricted by 95 C bulk outlet water temperature, current helium gas leak rates cause the graphite temperature to be optimum at 670 C (Figure 3). The annual economic incentive to lower the base graphite temperature to this value is about \$56,000.

While the study performed reveals a considerable dollar incentive by virtue of lower uranium throughput costs to reduce graphite temperature at the K Reactors, it did not consider the effects of graphite temperature on reactor life. Based upon data obtained from a graphite irradiation testing program for K Reactors, structural behavior with respect to expansion following extended periods of exposure appears to be temperature sensitive. Therefore, there may be additional incentive from reactor life considerations to reduce graphite temperatures at the K Reactors.

DISCUSSION

The use of helium as a constituent of the reactor gas atmosphere constitutes an economic parameter of substantial importance. If helium gas leak rates could be maintained at a relatively low rate, its economic impact would be insignificant. However, continued deterioration of the reactors' structural gas system allows considerable amounts of the gas to escape. Consequently, the gas costs result in an

* Adjusted net return is the value obtained when helium gas costs are included in the computerized results.

DECLASSIFIED

operating expenditure which is difficult to tolerate. This study was performed to determine the relationship between net return, helium loss, and graphite temperatures.

The economic evaluation was performed on the UNIVAC 1107 linear optimization computer code. The computer program does not include the helium gas loss costs which were subtracted from the computerized net return data to obtain an adjusted net return value. Appendix A contains input and output data of interest used in the 1107 LP calculations.

Basic assumptions and data used in the study were:

- 1) The side-to-side stringer temperature is directly proportional to the average moderator temperature.
- 2) A base case temperature of 720 C is representative of a standard weapons-grade plutonium loading.
- 3) An inlet water temperature of 9.5 C was assumed to be average for the months when reactor power level is administratively restricted.
- 4) Moderator temperatures remain constant throughout an operating period.
- 5) Reactor power level restricted by the administrative limit.
- 7) Helium gas costs of \$40/thousand cubic feet.
- 8) The relationship between helium concentration and helium gas losses, and maximum side-to-side stringer temperatures vary as shown in Figures 4 and 5 respectively.
- 9) Relationships and economics of the study are applicable to each K Reactor.
- 10) Helium gas costs from startup purges are not included in the economics.
- 11) Graphite temperatures and helium concentration vary with power level as shown in Figure 7.³
- 12) Enriched metal requirements as function of graphite temperature and gas composition vary as shown in Figure 6.⁴

With a "gas tight" K Reactor (no helium losses) there is a substantial economic incentive to reduce graphite moderator temperatures below the base case value. This is due to the significant savings obtained from the reduction in metal throughput costs. Metal throughput reductions result from the restriction to produce a constant Pu-240 concentration, which requires increased fuel discharge exposures as graphite moderator temperatures are lowered. Optimum graphite temperature for the production of six percent Pu-240 plutonium for zero gas loss occurs at 580 C. The economic incentive to lower the moderator temperature to this value is \$580/calendar day/reactor.

3. Personal communication with A. Russell.

4. Supplied by KE Reactor Physicist.

The economic impact that helium gas leak rates have on reactor operation requires serious consideration be given to methods by which the losses can be minimized. To accomplish a significant reduction in helium losses, operating expenditures are necessary. Before embarking upon an extensive gas system repair program, it is necessary to know the magnitude of savings to be expected from such a venture in order to justify the operating expenditure. For a weapons grade plutonium loading, an increase in annual net return of about \$212,000 per K Reactor is indicated for the case of zero gas losses. If a gas system repair method could effectively reduce current gas leak rates by 75 percent, an increase in annual return of about \$140,000/reactor would result.

Although reactor operation for this study was simulated for current administrative power level limit at an inlet water temperature of 9.5 C, the results would not be significantly different for other inlet water temperatures.

Shortly after completion of the original study, interest developed in the production of nondefense plutonium. Also, a relaxation in the administrative power level restriction at the K Reactors is anticipated. Additional computer runs were made to determine the economic effects of these changes in reactor operation with respect to optimum graphite temperatures and incentives for reducing gas losses.

Reactor operation with central-zone uranium fuel exposures to produce 12 percent Pu-240 plutonium at current helium gas leak rates provides no economic incentive to decrease graphite temperatures below the base case value. At the higher exposures required to produce 12 percent Pu-240, fuel failure downtime losses more than cancel out the gain in charge-discharge time. Also, the lower rate of plutonium production at these high exposures is enough to counteract the metal throughput savings. Consequently no incentive from a net return standpoint is realized at lower graphite temperatures. However, there is still incentive to reduce helium losses. Reducing the current helium gas leak rates by 75 percent results in an annual savings of about \$60,000 per K Reactor.

Operation with 94.5 bulk outlet water temperature and inlet coolant temperature of 12 C results in an optimum K Reactor graphite temperature of 670 C for current helium gas leak rates and 640 C for the case where gas losses are reduced 75 percent. The economic incentive to reduce gas losses 75 percent is \$460/calendar day. This is an average value. At winter inlet water temperatures a higher economic incentive will prevail, and the incentive will be lowest during the summer months.

Two other developments add incentive to reduce helium gas leak rates. Data obtained in Reactor Process Development's graphite irradiation program show that graphite contraction currently being experienced will eventually stop and will be followed by expansion. The time to reach this turnaround, and the rate of expansion following turnaround appears sensitive to temperature, thus, there may be incentive from a reactor life consideration to reduce graphite temperature with more helium. Additional data from this program will be available in November.

Also, considerable interest is being developed in the use of fully enriched fuels. This would result in increased gamma absorption and heat generation in the graphite and would surely require that the reactors operate with 100 percent helium. High power density operating modes using enriched drivers will require some additional helium to maintain graphite temperatures at current limits.

DECLASSIFIED

DECLASSIFIED

-7-

DUN-2994

DEL

L. J. Newell

L. J. Newell, Engineer
Reactor Process Development Unit
Reactor Engineering Subsection
Research and Engineering Section

LJN:ld

DECLASSIFIED

**DECLASSIFIED
WITH DELETIONS**

APPENDIX A

BASIC REACTOR OPERATING DATA

1. Reactor Flow, gpm - 216, 311
3. Metal Costs, \$/ton - 1954 for natural, 2169 for enriched
4. Power level limits - 4400 Mw and 94.5 bulk outlet
5. Inlet water temperature, °C - 9.5 and 12.0
6. Active number of tubes - 3013 with thoria target in fringe
7. Side-to-Side Stringer Temperature - °C
720 670 620
(base)
8. Discharge exposures, MWD/ton:

K5 Natural metal - 6% Pu-240	632	660	687
-12% Pu-240	1580	1650	1717
K4 Natural metal - 6% Pu-240	650	680	706
K5 Enriched metal - 6% Pu-240	890	930	965
K4 Enriched metal - 6% Pu-240	860	895	928

**DECLASSIFIED
WITH DELETIONS**

**DECLASSIFIED
WITH DELETIONS**

-9-

DUN-2994 **DEL**

LINEAR PROGRAM COMPUTER RESULTS FOR FIGURE 1

Inlet Water Temp. - °C	9.5	9.5	9.5
Max. Side-to-Side Stringer Temp. - C	720	670	620
Net Return - \$/Cal. Day	49,020	49,407	49,565
Plutonium Production - gms/Cal. Day	3145.1	3143.4	3134.2
Percent Pu-240 (entire reactor)	6	6	6
Production - MWD/Cal. Day	3562.7	3571.3	3577.1
Throughput Costs - \$/Cal. Day	10,567	10,138	9,739
<u>Throughput - Tons/Year</u>			
Natural Uranium	1699.1	1626.8	1543.9
Enriched Uranium	250.0	242.7	250.4
<u>Production Losses - %</u>			
Charge-Discharge	5.55	5.34	5.19
Tube Replacement	0.38	0.38	0.38
Fuel Failures	0.09	0.11	0.13
Miscellaneous*	13.00	13.00	13.00
Production Efficiency	80.97	81.16	81.30
<u>Net Return Adjustment For Current Helium Gas Losses</u>			
He Loss - cfm/Oper. Day	7000	11,900	19,900
He Loss - cfm/Cal. Day	5668	9658	16,179
He Cost - \$/Cal. Day	227	386	647
Adjusted Net Return	48,793	49,021	48,918

* Reactor downtime losses caused by production tests, maintenance work, projects, etc. - assumed to be constant.

**DECLASSIFIED
WITH DELETIONS**

DECLASSIFIED
WITH DELETIONS

-10-

DUN-2994

DEL

LINEAR PROGRAM COMPUTER RESULTS FOR FIGURE 2

Inlet Water Temp. - °C	9.5	9.5	9.5
Max. Side-to-Side Stringer Temp. - C	720	670	620
Net Return - \$/Cal. Day	48,044	48,011	47,818
Plutonium Production - gms/Cal. Day	2859.8	2845.4	2831.7
Percent Pu-240 (central natural fuel only - rest of reactor fuel at 6%)	12	12	12
Production - MWD/Cal. Day	3575.9	3569.1	3557.1
Throughput Costs - \$/Cal. Day	6,046	5,788	5,628
<u>Throughput - Tons/Year</u>			
Natural Uranium	853.7	812.8	766.9
Enriched Uranium	251.1	244.2	258.4
<u>Production Losses - %</u>			
Charge-Discharge	3.62	3.48	3.45
Tube Replacement	0.38	0.38	0.38
Fuel Failures	1.73	2.02	2.32
Miscellaneous*	13.00	13.00	13.00
Production Efficiency	81.27	81.12	80.84
<u>Net Return Adjustment For Current Helium Gas Losses</u>			
He Loss - cfm/Oper. Day	7000	11,900	19,900
He Loss - cfm/Cal. Day	5689	9653	16,087
He Cost - \$/Cal. Day	227	386	643
Adjusted Net Return	47,817	47,625	47,175

* Reactor downtime losses caused by production tests, maintenance work, projects, etc. - assumed to be constant.

DECLASSIFIED
WITH DELETIONS

**DECLASSIFIED
WITH DELETIONS**

-11-

DUN-2994 DEL

LINEAR PROGRAM COMPUTER RESULTS FOR FIGURE 3

Inlet Water Temp. - °C	12.0	12.0	12.0
Max. Side-to-Side Stringer Temp. - C	720	670	640 (100% He)
Net Return - \$/Cal. Day	51,924	52,323	52,443
Plutonium Production - gms/Cal. Day	3331.4	3328.9	3323.0
Percent Pu-240 (entire reactor)	6	6	6
Production - MWD/Cal. Day	3773.7	3782.0	3786.0
Throughput Costs - \$/Cal. Day	11,194	10,736	10,480
<u>Throughput - Tons/Year</u>			
Natural Uranium	1799.8	1722.8	1670.0
Enriched Uranium	265.0	257.3	261.0
<u>Production Losses - %</u>			
Charge-Discharge	5.88	5.65	5.55
Tube Replacement	0.61	0.61	0.61
Fuel Failures	0.25	0.31	0.34
Miscellaneous*	13.00	13.00	13.00
Production Efficiency	80.26	80.43	80.50
<u>Net Return Adjustment For Current Helium Gas Losses</u>			
He Loss - cfm/Oper. Day	11,400	19,000	26,500
He Loss - cfm/Cal. Day	9150	15,282	21,332
He Cost - \$/Cal. Day	366	611	853
Adjusted Net Return	51,558	51,712	51,590

* Reactor downtime losses caused by production tests, maintenance work, projects,
etc. - assumed to be constant.

**DECLASSIFIED
WITH DELETIONS**

DECLASSIFIED

-12-

DEL

FIGURE 1

AS A FUNCTION OF GRAPHITE TEMPERATURE AND
HELIUM GAS LEAK RATES

Reactor Power Level - 4400 Mw
Inlet Water Temperature - 9.5 C
Six Percent Pu-240 Plutonium

DECLASSIFIED

FIGURE 2

NET RETURN AS A FUNCTION OF GRAPHITE TEMPERATURE AND
HELIUM GAS LEAK RATES

Reactor Power Level - 4400 Mw
Inlet Water Temperature - 9.5C
K5N Discharge Exposures to Produce 12%

DECLASSIFIED

FIGURE 3

CONFIDENTIAL

DECLASSIFIED

NET RETURN AS A FUNCTION OF GRAPHITE TEMPERATURE AND
HELIUM GAS LEAK RATES

Reactor Power Level - 4702 Mw
Inlet Water Temperature - 12 C
6% Pu-240 Plutonium

FIGURE 4

HELIUM LOSS AS A FUNCTION OF REACTOR GAS COMPOSITION

DECLASSIFIED

FIGURE 5

DECLASSIFIED

RELATIONSHIP BETWEEN GRAPHITE STRINGER TEMPERATURE AND
HELIUM CONCENTRATION WITH REACTOR
POWER LEVEL AT 4400 MW

FIGURE 6

ENRICHED METAL REQUIREMENTS AS A FUNCTION OF
GRAPHITE TEMPERATURE AND NITROGEN CONCENTRATION

Base Point (Zero) assumes 50% Helium
and 50% Nitrogen

DECLASSIFIED

FIGURE 7

RELATIONSHIP BETWEEN GRAPHITE TEMPERATURE, GAS COMPOSITION
AND REACTOR POWER LEVEL

DECLASSIFIED

II

DATE

FILMED

8/23/94

END