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

DECLASSIFIED

(CLASSIFICATION)

DOCUMENT NO.

HW-59025

SERIES AND COPY NO.

20

DATE

March 13, 1959

GENERAL ELECTRIC

IC PRODUCTS OPERATION - RICHLAND, WASHINGTON

CLASSIFIED DATA
AINS RESTRICTED DATA AS
OMIC ACT OF 1954.
THE CLOSURE OF ITS
AN UNAUTHORIZED

TITLE

REACTIVITY TRENDS AND PREDICTION PROBLEMS VS
OPERATING TRENDS - C, H, KE, AND KW REACTORS
1954 THRU 1958

CLASSIFIED INFORMATION

AINS INFORMATION AFFECTING
SE OF THE UNITED STATES
OF THE ESPIONAGE LAWS,
CS. 793 AND 794, THE TRANS-
ON OF WHICH IN ANY MANNER
PERSON IS PROHIBITED BY

AUTHOR

D. E. Goins

ISSUING FILE

0
FEB 11 1959
FEB 11 1959
FEB 11 1959

LEFT UNATTENDED OR WHEN AN UNAUTHORIZED PERSON MAY HAVE ACCESS
IT MUST BE STORED IN AN APPROVED LOCKED REPOSITORY. APPROVED
E IT IS YOUR RESPONSIBILITY UNTIL YOU HAVE OBTAINED A SIGNED RECEIPT
T IS YOUR RESPONSIBILITY TO KEEP IT AND ITS CONTENTS WITHIN THE LIMITS
OM ANY UNAUTHORIZED PERSON. ITS TRANSMISSION AND STORAGE AT YOUR PLACE
HIBITED. IT IS NOT TO BE DUPLICATED. ADDITIONAL COPIES, IF REQUIRED,
HE REISSUING FILE. ALL PERSONS HANDLING THIS DOCUMENT ARE REQUESTED
PROCEED BELOW.

PAYROLL NO.

LOCATION

FILES ROUTE
DATE

SIGNATURE AND DATE

21202-59 J.E. 4-20-59
3689-17020 APR 28 1959

**RECORD
COPY**

Finite Retention

Disposal Date

Priority

Authority

MASTER

DECLASSIFIED

RICHLAND, WASH.

(CLASSIFICATION)

DECLASSIFIED

HW-59025

DISTRIBUTION

1. FW Albaugh	20. GR Gallagher	39. RE McGrath - JR Young
2. WG Albert - RW Bown	21. PF Gast	40. JS McMahon
3. ER Astley	22. DE Goins	41. DI Monnie
4. JT Baker	23. SM Graves	42. JF Music - P Thompson
5. JW Baker - WJ Ferguson	24. OH Greager	43. WS Nechodom
6. RS Bell	25. AB Greninger	44. SL Nelson - TM Hall
7. AG Blasewitz	26. CN Gross	45. R. Nilson
8. CW Botsford	27. RE Hall	46. GF Owsley
9. CE Bowers	28. WM Harty - RM Smithers	47. GR Parkos
10. JH Brown	29. TW Hauff	48. CA Priode - T Prudich
11. RD Carter	30. ET Hubbard - RK Wahlen	49. RW Reid
12. RA Chitwood	31. RT Jessen	50. DE Simpson
13. RG Clough - RJ Ascherl	32. PC Jerman	51. WR Smit
14. DL DeNeal	33. JE Kaveckis	52. HG Spencer
15. RL Dickeman	34. LW Lang	53. RE Trumble
16. RL Ferguson	35. CG Lewis - JR Pierce	54. AD Vaughn
17. EJ Filip - AP Vinther	36. DS Lewis - RL Sullivan	55. EC Wood
18. FC Franklin	37. AR Maguire	56. 300 Files
19. GC Fuller	38. WC McGee	57. Record Center

RESTRICTED DATA

This document contains restricted data as defined in Atomic Energy Act of 1954. Its transmittal or the disclosure of its contents in any form to an unauthorized person is prohibited.

This document consists of
54 pages, No. 20 of
57 copies. Series [redacted]

This document classified
by H. F. Curley

March 13, 1959

REACTIVITY TRENDS AND PREDICTION PROBLEMS VS. OPERATING TRENDS
C, H, KE, AND KW REACTORS - 1954 THRU 1958

INTRODUCTION

During the past several years higher pile power levels, variations in the uranium goal exposure, changes in reactor loadings, and resulting changes in operating practices have steadily increased reactivity transients following the reactor shutdowns and start-ups. Consequently, since conditions influencing reactivity transient predictions have become increasingly more varied, it has become more difficult to maintain prediction accuracy. Trends related to operating practices, reactivity variables, and critical predictions have been presented previously for the years 1950 through 1957 (1)*. It is the purpose of this report to include the data for the year 1958.

In addition to presenting the data for reference purposes, this document discusses the trends in (1) operating practices, (2) reactivity variable evaluations, and (3) the accuracy of reactivity predictions during the past five years. Bar graphs show the yearly averages of selected data obtained from the shutdown data sheets, monthly reports, and routine reactivity balance reports. In addition to these averages a table presents maximum and minimum values wherever they are applicable.

* References listed on Page 49.

DECLASSIFIED

DECLASSIFIED

HW-59025
Page 2

INTRODUCTION (Continued)

This document contains trends for C, H, KE, and KW Reactors. The companion document covering the other four reactors is HW-59024.

SUMMARY

From 1954 through 1958 pile power levels have doubled while the average spread of start-up reactivity prediction errors has remained about the same due to increased knowledge of reactivity variables. The major fields of improvement are: (a) calibration of horizontal control rods, (b) machine computation of effective reactivities, and (c) correlating the graphite reactivity coefficient with pile residual exposure. All trends in reactor operation are continuing in the direction of complicating reactivity predictions and thus tending to increase prediction errors. All factors indicate that more knowledge must be gained on reactivity effects in the future to hold prediction accuracy to the status that has been maintained in the past.

DISCUSSION

The Shutdown Data Sheets, issued by the area physicist for each pile outage exclusive of recovered scrams and temporary poison discharges, provide an excellent source of data for the study of reactivity and prediction trends as a function of operating conditions (2-5). Since the distribution of Shutdown Data Sheets is quite restricted, this document is intended to provide a reference for management and for other technical and operating personnel who do not have ready access to these data.

Data presented for the K Reactors for 1955 should not be indicative of normal operation since a major portion of the operation in this year was spent in making the transition from low power operation following the initial start-up to powers nearer the designed level. This is particularly true for KE pile where practically no uranium was discharged during the entire year to permit the measurement of plutonium reactivity gains as a function of the flux-squared weighted uranium exposure; however, the K piles data were included for 1955 to allow a rough estimate of trends that have occurred since the original start-up.

A recently discovered source of error is in evaluating the effective reactivity of enriched uranium charges. The flux-squared weighting procedure gives about twice the reactivity contribution as calculated from theory (10). This discovery (early 1959) is too new to say more at this time other than enrichment reactivity may only be half of that reported.

The graphs are shown in the order given on the following page. Each of the charts shows information either required in making transient predictions or having a direct bearing on the complexity of the prediction problem.

Classification Cancelled and Changed To

DECLASSIFIED

By Authority of D. S. Lewis

CG-PR-2, 12-20-93

By J. E. Savely 1-6-94

Verified By J. Maly, 1-24-94

DECLASSIFIED

Page 3

TABLE OF CONTENTS

I. OPERATING TRENDS

I-A	Pile Power Level	Page 4
I-B	Uranium Discharge Size	Page 6
I-C	Uranium Exposure Level	Page 8
I-D	Effective Full-Power Days	Page 10
I-E	Operating Period Duration	Page 12
I-F	Outage Duration	Page 14
I-G	Total Outage Time	Page 16
I-H	Number of Outages	Page 18
I-I	Average ECT	Page 20
I-J	Number of Scrams	Page 22
I-K	Average Scram Recovery Time	Page 24

II. TRENDS IN REACTIVITY VARIABLES

II-A	Reactivity in Control Rods	Page 26
II-B	Reactivity from Temperature Coefficients	Page 28
II-C	Reactivity in Flattening	Page 30
II-D	Temporary Poison Columns Used	Page 32
II-E	Fringe Poison and Enrichment Columns	Page 34
II-F	Enrichment Reactivity	Page 36
II-G	Enrichment Throughput	Page 38

III. START-UP CRITICAL PREDICTION TRENDS

III-A	Start-Up Pile Period Values	Page 41
III-B	Arithmetic Average Prediction Error	Page 43
III-C	Spread of Prediction Errors	Page 45

I. OPERATING TRENDS

This series of eleven charts shows that the indirect outage time effects of increasing pile power levels and varying exposure goals have complicated the reactivity prediction problem; this is in addition to the direct effects of larger transients.

I-A. Power Level History

The values in Figure I-A represent simple arithmetic averages of the recorded values of power level just before shutdown. These data are normalized to the old pile power level limit imposed by the ACRS (maximum power level at DR pile in 1957) during most of 1958. This limit is represented by unity on the chart. The values are taken from the shutdown data sheets for the calendar years noted. The power level just before shutdown is normally the equilibrium level if one was attained; therefore, the values in Figure I are representative equilibrium power level values averaged over one year; they are not maximum values. Many reactivity effects are a function of power level; therefore, if the relationship is not known accurately, the errors in the calculated reactivities will increase as the power level increases.

The rapid power level increases at the K Reactors have resulted primarily from approaching plant capacity by gradually increasing tube power limits since start-up in 1955. The decrease at C pile in 1957 resulted from a reduction in operating limits in September, 1956. This change (from trip before instability to rupture control) in limits was necessary when the average discharge exposure was raised.

DECLASSIFIED

DECLASSIFIED

HW 55000
Page 5

FIGURE I-A - AVERAGE POWER LEVEL JUST BEFORE SHUTDOWN

I-B Uranium Discharge Size

Figure I-B shows the average per cent of the pile discharged each outage that a discharge occurred based on flux-squared weighting of the discharge. This is only vaguely related to Figure I-A since the discharge size depends on shutdown frequency and target exposure. These averages are not simple numbers of tubes discharged, but are based on reactivity effects. Reactivity effects such as the discharge of iodine, xenon, neptunium, plutonium, promethium and samarium vary as the flux-squared or flux-cubed weighting. In most cases, the flux-squared and flux-cubed weighting discharge percentages are approximately equal.

DECLASSIFIED

DECLASSIFIED

FIGURE I-B - AVERAGE PER CENT OF PILE DISCHARGED EACH OUTAGE
(REACTIVITY WEIGHTED)

I-C. Uranium Exposure Level

The average exposure of the discharged natural uranium was obtained in the following manner:

$$\text{Average Exposure} = \frac{\sum_1 (\text{No. of Tubes in Discharge})(\text{Average Discharge Exposure})}{\sum_1 (\text{No. of Tubes in Discharge})}$$

where i = all discharges. (Outages where no discharge was made were not included.)

The average exposure of the discharged metal is important in two respects. The change in reactivity of the cold pile caused by replacing exposed fuel with fresh material is a function of the exposure of the discharged metal. In addition the reactivity of the hot pile is strongly influenced by uranium exposure. Since the discharge of exposed metal usually reduces the in-pile exposure, the exposure of the discharge has a marked effect on the reactivity of the hot pile. Although these effects have been recognized for some time, the relationships are not well known. The values for 1954 and 1955 are good approximations, but are not precise since the recorded information was not complete. In general, the flux-squared weighted exposure values are used for data since 1955 because the reactivity effects are more precisely related to these rather than to the averages of the arithmetic mean exposures.

DECLASSIFIED

DECLASSIFIED

HW-59025
Page 9

FIGURE I-C - AVERAGE EXPOSURE OF DISCHARGED METAL

Megawatt Days per Ton

I-D. Effective Full-Power Days

Figure I-D shows the number of effective full power days during the year. In this report this value is defined as the pile production for the year divided by the average power level just before shutdown. This number is of little or no value when working reactivity problems, but it is commonly used by many people concerned with operational efficiency problems.

The slight increase in 1957-58 over 1955-56 indicates increased start-up efficiencies by reducing the number of temporary poison outages and faster raises in power level following start-up.

The low values for the K piles in 1955 represent operation from initial start-up until the end of the year.

The comparatively low value for H pile in 1957 is attributed to the large tube replacement program and the long CG-558 outages. The low value for KW in 1958 can be attributed to the RTD outage lasting practically a full month.

DECLASSIFIED

Days

FIGURE I-D - EFFECTIVE FULL POWER DAYS IN YEAR (SEE TEXT FOR DEFINITION)

DECLASSIFIED

I-E. Duration of Operating Period

Figure I-E gives the average number of days operated between outages. Since about three days are required for a pile to reach equilibrium after start-up, it is obvious that many outages occur from non-equilibrium conditions. Consequently, reactivity calculations are more uncertain since transient values of the graphite contribution, iodine, and xenon are less well known than equilibrium values.

The comparatively lower values at C pile for 1957-58 and KE Reactor for 1957 have resulted from increased ruptured slug experience.

It is encouraging to note the increase in 1958 over 1957. This is due primarily to the changeover from solid to I & E fuel which reduced the rupture frequency. The associated higher goal exposure also permitted longer operating periods.

DECLASSIFIED

FIGURE I-E - AVERAGE NUMBER OF DAYS OPERATED BETWEEN OUTAGES

I-F. Duration of Outage

Figure I-F shows the average number of hours the pile was down for an outage*. This value is related to the amount of uranium discharged during the outage; it is also related to the operational problems such as ruptured slugs and water leaks. The outage duration has a direct bearing on reactivity prediction problems in that longer outages introduce greater uncertainties in rod evaluation, temporary poison, xenon evaluation, and temperature coefficients. Perhaps it would suffice to say that increased outage duration only makes more obvious the things we do not know.

* Such extremely long outages as re-orificing, water plant modification, tube replacement, etc., which started to become important in 1956, were omitted when finding the averages. These are listed by pile, year, and reason in Appendix I.

DECLASSIFIED

DECLASSIFIED

HW-590
Page 15

FIGURE I-F - AVERAGE OUTAGE DURATION

I-G. Total Outage Time

Figure I-G shows the total days down during each year. This includes the very long outages mentioned previously, but does not include the relatively small amount of time lost due to scrams or poison discharges since these are not routinely listed on all shutdown data sheets.

The comparatively large value at H pile in 1957 primarily results from the tube replacement program. Widespread tube replacement at C, KE, and KW piles has yet to become necessary.

DECLASSIFIED

HM-59025
Page 20

DECLASSIFIED

HW-59025

Page 17

FIGURE I-G - TOTAL TIME DOWN (NOT INCLUDING SCRAMS AND POISON DISCHARGE OUTAGES)

I-H. Number of Outages

Figure I-H shows the total number of outages each year which were of greater duration than ten hours. This automatically excludes scrams and poison discharge outages.

The relatively high values at C pile for all years and KE pile for 1957 have resulted from ruptured slug experience.

DECLASSIFIED

DECLASSIFIED

HW-55025
Page 19

FIGURE I-H - NUMBER OF OUTAGES MORE THAN TEN HOURS DURATION

I-I. Average ECT for Year

ECT is defined as :

$$\text{ECT} = \frac{\text{Total Reactor Power in Megawatts}}{\text{Average Maximum Tube Power in Megawatts}}$$

of ten most productive tubes.

These ECT values were averaged from monthly data presented in Reactivity Balance and Associated Data Reports (6)(7). The ECT value of the pile is important in determining relative flattening efficiency and thus equilibrium operating efficiency. Fluctuations in ECT are caused by block discharges, unbalanced rod configurations, and skewed flux distributions. It is interesting to note that ECT values have continued to climb, indicating more efficient equilibrium operation.

DECLASSIFIED

DECLASSIFIED

HW-59025
Page 21

FIGURE I-I - AVERAGE EFFECTIVE CENTRAL TUBES

I-J. Number of Scrams

The number of scrams at a reactor will tend to indicate frequencies of operational problems. Scrams result in losses of valuable production, and thus there is a great incentive to minimize their frequency. The Process Technology Operation maintains detailed records of scram causes and their effects on production.

DECLASSIFIED

DECLASSIFIED

HW
Page 23

Data not readily available prior to 1955

FIGURE I-J - NUMBER OF SCRAMS PER YEAR

I-K. Average Available Scram Recovery Time

In the event of a scram, recovery must be made within the very short amount of time before graphite cooling and xenon buildup render the pile sub-critical for approximately a day. The amount of time available for scram recoveries is dependent on pile power level, excess reactivity in rods during operation, and graphite temperature. There is a great incentive to maintain more available recovery time; however, pile power increases in the past few years have cost almost all available excess reactivity, and past enrichment limitations have prevented increasing pile reactivity at the K reactors. The I & E loading with increased power levels will tend to further reduce reactivity and thus scram recovery time unless it is "bought" with additional enrichment.

The comparatively large amount of available scram recovery time at H reactor is the result of a large enrichment inventory and limit.

The averages presented here are based on scram recovery time estimates made by the area physicists in their monthly reports.

DECLASSIFIED

HM-59025

Data Not Readily Available Prior to 1957

FIGURE I-K - AVERAGE AVAILABLE SCRAM RECOVERY TIME

DECLASSIFIED

II. TRENDS IN REACTIVITY VARIABLES

This series of charts shows the variations in reactivity contributions due to temperature coefficients and enrichment, the increases in control rod requirements for scram time and in temporary poison demands at start-up, and the resultant reactivity available for flattening columns.

II-A. Reactivity in Control Rods

Figure II-A shows the average reactivity in inhours held in the control rods just before shutdown. As the power levels increased, it became necessary to increase the equilibrium value of in-in-rods to maintain a reasonable scram time and also to be able to control the power distribution in the pile more efficiently. The use of the "half-rod" idea has improved the power distribution picture.

Until 1956 and 1957 reactivity predictions were based on control rod calibrations made during the original start-up when every known operating condition was different. In some cases the calibration curves were adjusted empirically by the area physicist to force agreement between his calculations and observations. Changes at H Reactor were made necessary by completely new rods that were installed in 1955. In April, 1956, the H Reactor area physicist revised the rod calibration curves, thereby increasing the estimated strength of the horizontal system by approximately 65 per cent. Similarly the C Reactor rod calibration curves were revised in June, 1957, thereby increasing the system strength by approximately 20 per cent. The graph shows the averages after these revisions. The estimates of the total worth of the horizontal system compared favorably with the values determined by period calibrations at H pile in January, 1957, and C pile in February, 1958. Incremental errors were found for equilibrium rod configurations during the calibration test at C pile which further increased their evaluation by approximately 20 per cent. The KW pile horizontal control rods were calibrated in May, 1957, and showed good general agreement with the evaluation determined during the initial start-up.

DECLASSIFIED

DECLASSIFIED

HW-59
Page 27

FIGURE II-A - AVERAGE REACTIVITY HELD IN RODS AT SHUTDOWN

II-B. Reactivity from Temperature Coefficients

Figure II-B shows the average value of the reactivity contribution to the pile as a result of temperature effects. Since the metal coefficient is negative and graphite coefficient is positive the value plotted is the difference between two numbers neither of which is well known. As power levels have increased, the reactivity lost to the metal coefficient has increased, but this has been off-set by increases in the graphite temperature. The dependence of the graphite temperature coefficient of reactivity on the exposure, or plutonium content, of the metal in the pile was derived theoretically in 1954, and it was firmly established in early 1955. It is now known that this effect has caused large prediction errors. In general, since late 1955, the area physicists have attempted to measure how the graphite coefficient varies with exposure. Critical predictions at start-up were forced to fit observed conditions by adjusting the values of the graphite contribution, then these values were plotted versus the flux-squared weighted exposures which have been provided by the Computing and Machine Records Operation since April, 1955. Nearly all predictions made since 1955 included corrections for the dependence of the graphite coefficient on exposure. Since the graphite coefficient was determined by forcing predictions to fit observed conditions, the magnitude of the coefficient will depend on the horizontal rod evaluations in use.

Changes to I & E loadings during 1958 decreased the metal coefficient (less negative) and increased the graphite reactivity contribution because of the higher goal exposures. Since these changes are averaged with solid fuel data, the changes are masked.

DECLASSIFIED

HW-59025
1958-10-25
1958-10-25

Inhours.

FIGURE II-B - AVERAGE REACTIVITY FROM OVERALL TEMPERATURE COEFFICIENTS

DECLASSIFIED

II-C. Reactivity in Flattening

Figure II-C shows average flattening values by pile and year. The values include all non-power tubes inside the active region of the pile except fringe shield poison whether they are strictly a part of the flattening pattern or not. The values plotted are the "effective" reactivities listed in Reactivity Balance documents. The effective reactivity value is a function of the pile neutron flux distribution as well as the quantity of absorber in the tubes. The conversion from known nominal values to "effective" values has been done almost entirely by rules-of-thumb and approximations since accurate calculations require either a great deal of time or fast machine computation. In 1955 a reactivity accounting test based on machine calculations confirmed the results of hand-calculated spot-checks. It is apparent that fairly large errors were possible in flattening changes. In November, 1956, a system was adopted for calculating the reactivity in flattening and enrichment based on flux-squared weighting information provided each month by the Computing and Machine Records Operation. Flattening material nominal reactivities measured during the initial C pile start-up were adopted for H Reactor at that time.

DECLASSIFIED

DECLASSIFIED

HW-5902
Page 31

FIGURE II-C - AVERAGE FLATTENING AND OTHER NON-URANIUM COLUMNS IN PILE

II-D. Temporary Poison Columns Used

Figure II-D shows the average number of temporary poison columns used each temporary poison start-up. None are needed for a minimum outage, and the number required increases with downtime up to about three days down. The poison strength of a column depends upon its location in the pile; therefore, the number required will also depend upon the locations of the columns. In the practical case the maximum number of columns varies from 15 to 20. Currently it is not possible to predict with precision the reactivity effect of a poison column, and it does not appear that a satisfactory method which will cover all cases is possible. Particularly as the reactors become more enriched, individual strengths can vary $\pm$ 35 per cent from the "best value." As it is, errors as great as 100-200 ih in critical have resulted from temporary poison column evaluations. Equally significant is the fact that a compensating 100-200 ih error may be hidden by such large assumed values for temporary poison which would manifest itself at some other time when temporary poison was not used.

Data are not presented for H pile start-ups utilizing the Poison Column Control Facility since poison column strengths are variable during start-ups. The installation of the Poison Column Control Facility at H pile in 1957 has greatly reduced the frequency of temporary poison column usage. The poison spline system installation that began will increase supplemental reactivity control and further reduce temporary poison column demands.

DECLASSIFIED

DECLASSIFIED

HW-59

Page 55

FIGURE II-D - AVERAGE NUMBER OF TEMPORARY POISON COLUMNS USED EACH START-UP REQUIRING TEMPORARY POISON

II-E. Fringe Poison Columns and Compensating Enrichment

With increasing pile power levels, biological shield damage has also increased. Fringe poison columns were charged at those reactors having the greatest shield damage in order to reduce shield temperatures and thus increase their life. Enrichment columns were also charged to compensate for reactivity losses associated with the shield protecting poisons.

This graph presents averages of fringe poison and enrichment columns beginning on their charge dates and continuing through the year.

The C, KE, and KW piles do not require fringe poison for shield protection since they were constructed with a water-cooled biological shield.

DECLASSIFIED

DECLASSIFIED

HW-10025
Page 5

E COLUMNS

POISON COLUMNS

FIGURE II-E - AVERAGE NUMBER OF FRINGE POISON COLUMNS AND COMPENSATING E COLUMNS

II-F. Enrichment Reactivity

This graph shows the average month end reactivity inventory of enriched uranium. All enrichment prior to 1957 was in the form of U-235 aluminum alloy columns (C), which, when freshly charged, contained 0.49 kg of U-235 at the C and H piles, and 0.59 kg of U-235 at the K Reactors. No correction for burnout was made on the C material. Since the C columns were normally irradiated to 35-40 per cent burnout, an average for the entire radial pattern should be about 15-20 per cent. In 1957 a program was initiated to replace all C material with enriched uranium (E) containing 0.94% U-235. The changeover was practically complete at the end of 1957. Reactivity-wise a C column is equivalent to approximately three E columns. In general the enrichment inventory has increased with power level; however, it is also influenced by the uranium goal exposure as demonstrated in the case of C pile which reduced its investment after going off the low goal program.

This graph does not include enrichment charged to compensate for fringe poison shield protection.

The reactivity values assigned to the radial enrichment may be about 50 per cent too great according to studies made early in 1959(10). It seems that the flux-squared weighting technique has been pushed beyond the point of applicability. This problem should be resolved in 1959.

DECLASSIFIED

HT-50035
1-7-59
1-7-59
1-7-59

DECLASSIFIED

HW-59025

Page 27

FIGURE II-F - ENRICHMENT REACTIVITY - EXCLUDING FRINGE POISON COMPENSATION

II-G. Enrichment Discharged

The number of enrichment columns discharged is determined by reactor power level, total number of columns, and changes in goal exposure and graphite temperature limits. This graph shows the total number of both "E" and "C" columns discharged (including fringe enrichment). A "C" column will remain in the reactor about three times as long and be worth about three times the reactivity of an "E" column. Therefore, every "C" column discharged is equivalent to approximately nine "E" columns. There were no "C" columns in use at the end of 1958.

The large number of "E" columns discharged at KW Reactor in 1957 is indicative of a greater number of C columns replaced with E enrichment earlier in the year than at the other reactors.

DECLASSIFIED

FIGURE II-G - TOTAL NUMBER OF ENRICHMENT COLUMNS DISCHARGED EACH YEAR

DECLASSIFIED

HW-59025
Page 39

III. START-UP CRITICAL PREDICTION TRENDS

The elements of a reactivity prediction are:

1. Power level
2. Δk in rods before shutdown
3. Xenon and Iodine
4. Graphite coefficient
5. Metal coefficient
6. Neptunium-Plutonium transients
7. Promethium-Samarium transients
8. F^2 and F^3 weighted discharge sizes (where F refers to relative tube power factors)
9. Flattening changes
10. Enrichment changes
11. Reactivity effect of uranium vs. exposure

Some are not listed directly, but since they are power level dependent they are known if the power level history is known. Each of the items except 6, 7, and 8 are dependent on the data in preceding charts. Items 6 and 7 are of opposite sign and their difference is not large, consequently these items are not included normally in prediction calculations. Item 8 is handled by machine computation and the accuracy is probably as high as the basic flow and temperature data and time will permit.

DECLASSIFIED

III-A. Start-Up Period

Figure III-A shows the average magnitude of the reported start-up period in inhours. There appears to be no good reason why this value should decrease as operating level, exposure, shutdown length or anything else increased. The decrease can be explained in part by the increased sensitivity of the Proportional Counters. At C and H Reactors, the PC chamber position was made mechanically independent of other chamber positions in late 1954, and the level of maintenance was improved; since 1955 routine testing of new equipment of increased sensitivity installed in 1955 established that good sensitivity was maintained.

Prediction accuracy, accurate rod calibrations, and adequate instrument sensitivity provide the greatest assurance that start-ups will be made on reasonably slow rising periods. As a result, less conservative rod withdrawal procedures have been placed in use.

One further note on pile periods is desirable; the period listed on the shutdown data sheet is not always the initial start-up period. On infrequent occasions when the prediction error and/or lack of instrument sensitivity was such as to produce a fast initial period, the pile has been scrambled by the Beckmans before the period could be evaluated. In this case, the subsequent period is listed with the associated rod value. This means that the actual average and maximum values for the initial start-up periods are in some cases larger than those listed.

DECLASSIFIED

DECLASSIFIED

HW-590
Page 42

FIGURE III-A - AVERAGE COLD START-UP RISING PERIOD

III-B. Arithmetic Average Prediction Error

Figure III-B shows the arithmetic averages of the prediction errors. Here prediction error is defined as "the pile reactivity at start-up" minus "the predicted pile reactivity at start-up." Both positive and negative errors occur, and the yearly average for each pile should be approximately zero. When errors occur, corrections are made to the "working constants" to cause agreement and the new values are used until further errors occur or until elements used in making predictions can be measured more accurately. Ordinarily this will keep predictions scattered about the true values.

In general the magnitudes of the averages of the prediction errors have increased as the average power levels before shutdown. As the scatter of predictions about the true values decreases, the arithmetic averages can be expected to be both positive and negative. The "scatter" of predictions about true values is shown in Figure III-C.

The prediction error is also dependent on the calibration of the horizontal rod system. One would expect prediction errors to increase after increasing HCR evaluations. In order to truly compare the data for the past five years, the magnitudes of the data prior to the HCR calibration tests should be increased by an equivalent amount as indicated in these tests. With the difference in mind, a more significant reduction in prediction errors has occurred than is indicated by the graph.

Large negative prediction errors resulting from known leaking process tubes have been omitted from the averages presented in this graph.

DECLASSIFIED

DECLASSIFIED

HW 20025
Page 44

FIGURE III-B - ARITHMETIC AVERAGE OF PREDICTION ERRORS

III-C. Spread of Prediction Error

Figure III-C shows the "spread" or "scatter" of prediction errors about zero by use of the root-mean-square value of the year's errors. The rather abrupt decrease in 1956 is attributed to corrections for the variation of the graphite coefficient with exposure. This was the first full year that this correction had been made routinely at all piles.

The apparent increase in errors in 1957 can be partially attributed to the change in rod calibrations. If the errors prior to 1956 and 1957 are increased at H and C piles respectively by approximately 50 and 20 per cent, a truer comparison of trends can be made.

Large negative prediction errors resulting from known leaking process tubes have been omitted from the averages presented in this graph.

DECLASSIFIED

DECLASSIFIED

HW-59025
Page 46

FIGURE III-C - RMS VALUE OF PREDICTION ERROR

DECLASSIFIED

HW-59025

Page 47

CONCLUSIONS

The bar graphs show that during the last five years nearly all of the operating and reactivity variable trends have continued in directions tending to make accurate reactivity predictions more difficult. Since there is every reason to expect these trends to continue, and since observation indicates errors in some or all of the components of the reactivity calculations, there is a continuing need to measure a number of the variables with greater accuracy than they are now known. More precise values for these variables should provide a reduction of the spread in prediction errors and thereby improve pile safety and in some cases permit higher operating efficiencies.

All three start-up critical prediction trends show considerable improvement in either 1956 or in both 1955 and 1956 and by considering rod calibration changes, 1957. Rod calibration tests in 1956 provided information which improved prediction accuracy in 1957; however, the real improvement was masked by the switch from the old set of calibrations to the new ones, since the new calibrations are approximately 65 per cent stronger for the same rod configuration.

Following is a listing of the current status of efforts to increase the accuracy of our knowledge of prediction variables.

1. The horizontal rod system has been calibrated by pile period measurements at C, H, and KW Reactors. The current trends toward increased enrichment loading, fringe poison, increased charge length, and I & E loadings will partially invalidate the rod calibrations in the future. Additional rod calibration tests will be desirable in the future when pile operating conditions undergo a significant change.
2. The graphite temperature reactivity contribution has been expressed as a power coefficient (inhours per megawatt) in the past. This relationship is subject to larger errors than one based on temperature. An effort to base the graphite coefficient on temperature (inhours per degree) will be made during 1959.
3. The reactivity accounting system based on tube factors has been pushed beyond the range of applicability. The enrichment evaluation based on tube factors is about twice that theoretically calculated. A new system for reactivity accounting needs to be devised. Work on this project will begin in 1959.
4. One of the large uncertainties in reactivity transient predictions is the metal temperature or power coefficient of reactivity. It would be desirable to determine experimentally this factor in 1959. Since metal temperature changes result in immediate reactivity changes, such tests should not require appreciable amounts of reactor downtime.
5. Recent information (8) has invalidated the currently used inhour versus period equation for U-235 and makes the pile relationship more exposure dependent. It would also be desirable to change all reactivity accounting from inhours to milli-k units and thus obtain a more consistent system of reactivity accounting. This change is a goal for 1959.

DECLASSIFIED

HW-59025
Page 48

CONCLUSIONS (Continued)

6. It has long been recognized that data taken during start-ups from minimum outages are the most valid for determining needed reactivity coefficient information. A production test (9) has been issued to increase collection of this type of data. As an expected result, prediction accuracies should increase in the future.
7. The increased discharge goal exposure associated with the I & E loadings will increase reactivity variations. This trend will further complicate reactivity transient predictions and tend to increase prediction errors.
8. It must be emphasized that positive and reliable start-up instrumentation is an ultimate protection whose achievement is worthy of high priority effort.

DE Goins

Operational Physics Operation
Research and Engineering
IRRADIATION PROCESSING DEPARTMENT

DE Goins:mwe

DECLASSIFIED

HW-59025
Page 49

REFERENCES

1. HW-41488/1950-1955; HW-48410/1950-1956; HW-54416/1953-1957, "Reactivity Trends and Prediction Problems vs. Operating Trends."
2. HW-6563-L/1954; HW-34392/1955; HW-40300/1956; HW-47238/1957; HW-54074/1958, "Shutdown Data Sheets - 105-C."
3. HW-6567-L/1954; HW-34396/1955; HW-40304/1956; HW-47242/1957; HW-54079/1958, Shutdown Data Sheets - 105-H."
4. HW-34397/1955; HW-40305/1956; HW-47243/1957; HW-54076/1958, "Shutdown Data Sheets - 105-KE."
5. HW-34398/1955; HW-40306/1956; HW-47244/1957; HW-54075/1958, "Shutdown Data Sheets - 105-KW."
6. "Reactivity Balance and Associated Data," reported monthly beginning with HW-30966 for January-February, 1954, and ending with HW-45109 for July-August, 1956.
7. "Reactivity Balance and Associated Reactor Physics Data," reported monthly beginning with HW-45935 for September, 1956, and continuing through HW-58707 for December, 1958.
8. LA-2118, "Delayed Neutrons from Fissionable Isotopes of Uranium, Plutonium, and Thorium," G. R. Keepin, et al, July 23, 1957.
9. HW-51799, "PT-IP-105-C, Graphite Power Coefficient Determination," G. R. Parkos, 8-30-57.
10. Private communication from G. R. Parkos.

DECLASSIFIED

HW-59025
Page 50

APPENDIX I

List of long outages not included in other listings.

C File

November, 1954	<u>226 hours</u> to replace pigtails.
September, 1955	<u>158 hours</u> to recover balls from 3X channels.
July, 1957	<u>242 hours</u> for CG-651.
September, 1957	<u>80 hours</u> for rupture removal and maintenance.
February, 1958	<u>80 hours</u> for HCR calibration.
April, 1958	<u>61 hours</u> for rupture and maintenance.
July, 1958	<u>136 hours</u> for miscellaneous maintenance.

H File

August, 1955	<u>285 hours</u> for HCR and venturi installation.
October, 1955	<u>253 hours</u> for ball recovery from 3X channels.
January, 1956	<u>272 hours</u> for tube replacement.
April, 1956	<u>135 and 222 hours</u> for tube replacement.
June, 1956	<u>142 hours</u> for tube replacement.
July, 1956	<u>135 and 307 hours</u> for tube replacement.
September, 1956	<u>138 hours</u> for tube replacement.
December, 1956	<u>133 hours</u> for tube replacement.
January, 1957	<u>75 hours</u> for KAPL-120 loop removal and HCR calibration.
February, 1957	<u>96 hours</u> for tube replacement.
March, 1957	<u>179 hours</u> for tube replacement.
April, 1957	<u>124 hours</u> for tube replacement.
May-June, 1957	<u>1287 hours</u> for CG-558 water plant expansion.
July, 1957	<u>148 hours</u> for tube replacement.
August, 1957	<u>92 hours</u> for tube replacement.
September, 1957	<u>86 hours</u> for tube replacement;
	<u>78 hours</u> for excessive number of ruptures.
November, 1957	<u>67 hours</u> for tube replacement.
March, 1958	<u>79 hours</u> for tube replacement.
April, 1958	<u>384 hours</u> for removal of a cored "E" metal rupture.
July, 1958	<u>79 hours</u> for tube replacement and KAPL-120 loop decontamination.
September, 1958	<u>73 hours</u> for miscellaneous maintenance.

KE File

April, 1955	<u>76 hours</u> to repair outfall line.
October, 1955	<u>201 hours</u> for pigtail replacement.
January, 1956	<u>86 hours</u> for inspection of back-up generators.
July, 1956	<u>87 hours</u> for rupture removal and repair of tube leak.
December, 1956	<u>233 hours</u> to put the KER facility into operation.
July-August, 1957	<u>79 hours</u> for rupture removal and maintenance.
August, 1957	<u>72 hours</u> for rupture removal and maintenance.
February, 1958	<u>121 hours</u> for nozzle reaming and maintenance.
March, 1958	<u>73 hours</u> for rupture and tube replacement.
August, 1958	<u>74 hours</u> for miscellaneous maintenance.

DECLASSIFIED

HW-59025
Page 51

APPENDIX I (Continued)

KW File

January, 1955	<u>64.5 days</u> as a result of the KW incident.
April, 1955	<u>77 hours</u> to repair outfall line.
June, 1955	<u>89 hours</u> for reactor maintenance.
July, 1955	<u>111 hours</u> for leak testing.
September, 1955	<u>333 hours</u> for pigtail replacement.
January, 1956	<u>88 hours</u> for repair and inspection of back-up generators.
January, 1957	<u>70 hours</u> for reactor maintenance.
May, 1957	<u>40 hours</u> for HCR calibration.
July, 1957	<u>63 hours</u> for reactor maintenance
	<u>57 hours</u> for ball recovery from 3X channels.
October, 1957	<u>73 hours</u> for reactor maintenance.
November, 1957	<u>68 hours</u> due to Panellit grounding and reactor maintenance.
	<u>62 hours</u> for scheduled outage and reactor maintenance.
December, 1957	<u>125 hours</u> for rupture removal and miscellaneous maintenance, (two outages).
January, 1958	<u>68 hours</u> for miscellaneous maintenance.
November, 1958	<u>28.3 days</u> for RTD and gas seal replacement.

APPENDIX II - TABLE OF MAXIMUM - AVERAGE - MINIMUM VALUES

CALENDAR YEAR			1954		1955			
PILE			C	H	C	H	KE	KW
Pile Power Level before Shutdown (Normalized)	Max.		1.07	.68	1.13	.80	1.40	1.40
	Avg.		.85	.58	.94	.70	.84	.92
	Min.		.63	.38	.42	.49	.42	.69
Uranium Discharge Size in Per Cent of Pile	Max.		36.8	23.5	34.5	30.7	10.7	28.1
	Avg.		14.6	12.9	8.3	13.9	10.7	19.3
	Min.		1.0	2.0	1.0	2.0	10.7	2.5
Uranium Exposure Level in Megawatt Days per Ton	Max.		900	675	900	1435	700	260
	Avg.		317	383	242	380	700	253
	Min.		190	193	150	207	700	130
Effective Full Power Days (1)	-		252	315	245	267	220	216
Duration of Operating Period in Days	Max.		14.9	31.4	9.79	24.2	51.2	35.8
	Avg.		4.6	11.9	3.63	8.5	10.2	8.8
	Min.		0.1	0.1	0.1	0.2	2.0	0.9
Duration of Outage in Hours (2)	Max.		87.8	136##	92.6	123	71.5	78.9
	Avg.		37.7	46.7	38.1	48.6	31.9	39.2
	Min.		10.6	22.2	14.3	12.4	13.5	19.7
Total Outage Time (3)(Days)	-		91.1	56.4	113.0	85.2	35.0	123.1
Number of Outages (3)	-		53	29	69	33	21	27
Reactivity in Control Rods in Inhours	Max.		434	271	541	240	466	321
	Avg.		241	191	245	204	307	180
	Min.		105	110	146	156	132	23
Reactivity from Temperature Coefficients in Inhours	Max.		407	460	434	512	452	262
	Avg.		336	343	345	385	292	192
	Min.		187	262	173	294	108	110
Reactivity in Flattening in Inhours	Max.		317	692	236	646	383	131
	Avg.		133	569	182	409	206	49
	Min.		12	410	128	263	8	2
Number of Temporary Poison Columns Used	Max.		10	13	8	12	26	12
	Avg.		7	11	7	8	11	8
	Min.		6	8	4	4	6	7
Pile Period at Start-up in Inhours	Max.		70	90	68	57	41	40
	Avg.		45	54	36	31	23	26
	Min.		19	20	14	10	9	3
Prediction (+/-)	Max.		84/109	66/137	79/186	198/86	86/146	98/170
Error in Inhours	Avg.		0	-36	-15	+34	-21	-18
	Min.		-109	-3	0	-1	+1	0
RMS Prediction Error	-		39	68	52	70	57	55

(1) See page 10 for definition.

(2) The values here do not include the outages listed in Appendix I.

(3) The values here include the outages in Appendix I but do not include recovered scram or poison discharge outages.

Accidental damage to large number of Panellit gages.

DECLASSIFIED

APPENDIX II - TABLE OF MAXIMUM - AVERAGE - MINIMUM VALUES (Continued)

CALENDAR YEAR		1956				1957			
PILE		C	H	KE	KW	C	H	KE	KW
Pile Power Level before Shutdown (Normalized)	Max.	1.20	.83	1.88	1.88	1.09	.92	2.10	2.18
	Avg.	1.03	.74	1.48	1.48	.92	.84	1.73	1.97
	Min.	.49	.5	.85	1.18	.38	.69	.73	1.33
Uranium Discharge Size in Per Cent of Pile	Max.	34.5	39.6	27.4	25.9	22.4	27.0	28.8	25.6
	Avg.	18.1	10.3	11.4	13.5	9.7	13.9	11.1	13.2
	Min.	1.0	1.0	1.7	2.8	1.3	1.0	1.9	3.3
Uranium Exposure Level in Megawatt Days per Ton	Max.	497	823	800	845	725	629	541	566
	Avg.	296	537	690	635	519	492	479	506
	Min.	239	252	265	253	300	291	316	425
Effective Full Power Days(1)		267	254	287	303	285	240	294	290
Duration of Operating Period in Days	Max.	18.3	27.8	26.7	27.1	22.7	25.4	17.1	19.8
	Avg.	5.4	8.9	9.1	11.6	5.6	9.5	5.6	9.6
	Min.	0.1	0.4	1.3	2.4	0.1	1.3	0.2	1.9
Duration of Outage in Hours (2)	Max.	79.4	85.2	73.4	68.8	66.2	55.2	62.7	53.4
	Avg.	38.4	38.8	37.3	40.9	34.9	31.4	34.7	35.4
	Min.	13.5	20.8	23.0	23.4	11.3	21.1	16.0	25.7
Total Outage Time(3) (Days)		80.1	97.4	65.2	48.0	74.8	112.7	76.1	57.3
Number of Outages (3)		50	30	34	27	51	25	51	32
Reactivity in Control Rods In Inhours	Max.	337	758	440	350	362	688	250	347
	Avg.	193	567	267	269	311	523	228	231
	Min.	128	449	163	207	243	347	184	186
Reactivity from Temp. Coefficients In Inhours	Max.	400	595	382	457	658	598	440	396
	Avg.	340	394	293	357	587	468	362	303
	Min.	275	275	205	170	504	327	268	161
Reactivity in Flattening in Inhours	Max.	225	658	260	228	162	409	92	102
	Avg.	127	492	69	133	65	309	51	34
	Min.	37	356	7	3	23	150	13	13
Number of Temporary Poison Columns Used	Max.	14	14	22	16	10	13	20	21
	Avg.	9	9	17	13	9	12	17	18
	Min.	6	6	10	10	8	10	16	16
Pile Period at Start-up in Inhours	Max.	49	72	63	56	64	112	53	47
	Avg.	23	28	27	30	24	26	31	24
	Min.	3	10	11	8	0	8	15	11
Prediction (+/-) Error in Inhours	Max.	48/93	111/89	118/113	43/82	95/91	140/58	181/143	70/77
	Avg.	-17	-5	-19	-2	-10	+14	+0.5	-11
	Min.	+1	+1	-1	+1	0	0	0	-3
RMS Prediction Error		38	50	50	26	40	50	59	32

(1) See page 10 for definition.

(2) The values here do not include the outages listed in Appendix I.

(3) The values here include the outages in Appendix I but do not include recovered scram or poison discharge outages.

DECLASSIFIED

DECLASSIFIED

HW-59025
Page 54

APPENDIX II - TABLE OF MAXIMUM - AVERAGE - MINIMUM VALUES (Continued)

CALENDAR YEAR			1958			
	PILE		C	H	KE	KW
I. Operating Trends	Pile Power Level	Max.	1.21	1.00	2.18	2.18
	Before Shutdown	Avg.	1.00	.92	1.98	1.92
	(Normalized)	Min.	.31	.63	.97	1.04
	Uranium Discharge	Max.	19.9	28.9	29.2	28.0
	Size in Per Cent	Avg.	7.0	12.9	9.9	10.1
	of Pile	Min.	.1	1.0	.9	1.1
	Uranium Exposure	Max.	805	563	800	798
	Level in Megawatt	Avg.	699	470	547	641
	Days per Ton	Min.	408	221	106	457
	Effective Full Power Days (1)		293	240	282	268
	Duration of Operating	Max.	17.1	20.8	28.9	24.8
	Period in	Avg.	6.3	8.8	8.6	8.0
	Days	Min.	.2	.4	.2	1.1
	Duration of Outage	Max.	64.4	60.0	73.8	61.7
	in Hours (2)	Avg.	39.2	34.7	41.6	35.5
		Min.	14.9	8.0	23.5	20.4
	Total Outage Time (3) (Days)		78.4	63.2	66.6	81.6
	Number of Outages		45	30	35	35
II. Trends in Reactivity Variables	Reactivity in	Max.	413	621	388	440
	Control Rods	Avg.	349	481	249	281
	in Inhours	Min.	251	363	208	198
	Reactivity from	Max.	839	599	688	477
	Temp. Coefficients	Avg.	621	477	375	347
	in Inhours	Min.	523	413	219	161
	Reactivity in	Max.	101	552	131	95
	Flattening	Avg.	55	397	56	42
	in Inhours	Min.	34	276	27	17
	Number of Temporary	Max.	8	--	21	21
	Poison Columns	Avg.	8	--	19	18
	Used	Min.	8	--	15	8
III. Critical Pred. Trends	Pile Period	Max.	64	45	63	53
	at Start-up	Avg.	28	14	31	28
	in Inhours	Min.	5	4	10	10
	Prediction (+/-)	Max.	156/200	163/87	88/93	73/100
	Error	Avg.	11	24	-8	2
	in Inhours	Min.	-2	0	1	1
	RMS Prediction Error		66	68	45	42

- (1) See page 10 for definition.
- (2) The values here do not include the outages listed in Appendix I.
- (3) The values here include the outages in Appendix I but do not include recovered scram or poison discharge outages.

**DATE
FILMED**

10/26/94

END