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TITLE

PRODUCTION LOSSES AND REACTOR PERFORMANCE AT THE HANFORD REACTORS

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PRODUCTION LOSSES AND REACTOR PERFORMANCE AT THE
HANFORD REACTORS

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Reference:

Confidential Undocumented - "A System for Monitoring Operating Efficiency of the Hanford Reactors." April 6, 1956, C. W. Botsford to O. C. Schroeder.

INTRODUCTION

Reactor performance currently is being measured primarily by the time operating efficiency. However, the time operating efficiency reveals only a partial picture of the overall reactor performance, since it indicates only the amount of time that the reactor is operating and indicates nothing concerning actual efficiency while operating. True efficiency is measured by the amount of production accomplished with respect to the production potential of the facility. To present a more accurate picture of reactor performance, two types of losses need to be examined in addition to losses resulting from normal outages. These are: 1) losses during non-equilibrium operating conditions and 2) differences between plant potential level and the actually achieved equilibrium level. Losses of these types have been reported to the Process Evaluation Group by the Reactor Operations Physicists according to the procedure specified in the reference document. The purpose of this document is to report the results of an analysis of these data for the period of May through June, 1956, to determine the uses of this type of analysis, and to determine if such data should be collected and analyzed routinely.

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CONCLUSIONS AND RECOMMENDATIONS

Four additional efficiency numbers were developed to give a more accurate measure of reactor performance than can be obtained from examination of time-operating-efficiency and are essential for the proper evaluation of items which may affect reactor production. These calculated efficiencies are as follows:

1. Reactor Efficiency

Production potential is defined as the maximum production which could be accomplished during a given period. This involves operating 100 per cent of the time at the maximum power level possible utilizing the optimum number of effective central tubes. Using the preceding definition the reactor efficiency can be defined as the ratio of the actually achieved production to the production potential. The reactor efficiency during the period covered by this report was only 61.5 per cent. This number is the true indication of overall reactor performance.

2. Production Efficiency

Production efficiency is based on the attained equilibrium production level rather than the potential level. The production efficiency is the actual production divided by the production obtainable from operating 100 per cent of the time at the attained equilibrium power levels. The production efficiency during the period of this report was 69.4 per cent. This number is primarily an indication of the losses, both actual shutdown losses and non-equilibrium losses, resulting from shutdowns.

3. Operating Efficiency

The operating efficiency, not to be confused with time-operating-efficiency or any similar term, is a measure of the non-equilibrium losses, primarily those losses subsequent to startups. It is obtained by dividing the actual production by the production which would have been attained if there had been no non-equilibrium losses. The operating efficiency during the period covered by this report was 89.2 per cent.

4. Level Efficiency

The level efficiency is a measure of how close the attained power level approached the potential power level during reactor operation. It is an indication of the equilibrium level losses. The level efficiency during the period covered by this report was 88.6 per cent.

The reactor production losses determined in this report are presented in detail in Table I and are summarized on the following page:

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SUMMARY OF REACTOR SECTION PERFORMANCE

<u>Annual Losses</u>	<u>Units - MWD</u>	<u>Value *</u>
Non-equilibrium loss	317,000	\$ 3,810,000
Equilibrium loss	391,000	4,690,000
Shutdown equilibrium loss	103,000	1,240,000
Actual shutdown loss	<u>839,000</u>	<u>10,100,000</u>
Total Losses	1,650,000	\$19,840,000
Actual production	<u>2,610,000</u>	<u>\$31,300,000</u>
Production potential	4,260,000	\$51,140,000

Further analysis of the data in Table I reveals:

100-K Reactors non-equilibrium loss	208,000	\$ 2,496,000
100-K Reactors equilibrium loss	231,000	2,772,000
100-K Reactors actual shutdown loss	185,000	2,220,000

* Based on \$12/per MWD.

Analysis of these data reveals that there are substantial gains to be made; perhaps more than is generally realized. As noted above, the losses due to reactor shutdowns, which include both actual shutdown loss and the non-equilibrium losses, accounted for 27.1 per cent of the potential production or approximately \$14,000,000 annually. The non-equilibrium loss due to shutdowns alone is worth nearly \$4,000,000 per year. The equilibrium level loss (the difference between the optimum power level and the attained power level) is over \$4,000,000 per year. At the 100-K Reactors the non-equilibrium loss alone is greater than the actual shutdown loss. As noted in Table II, the average non-equilibrium loss for a 100-K Reactor following a hot startup is about 2100 MWD and about 1800 MWD following a cold startup. This means that each hot startup and cold startup costs about \$25,000 and \$22,000 respectively in non-equilibrium losses alone. These large losses at the 100-K Reactors are due primarily to non-equilibrium scrams, and heat cycles following startup.

These figures show that there is ample justification for reducing equilibrium level losses and non-equilibrium losses. There is nearly as much justification for reducing these losses as there is for reducing actual shutdown losses.

The basic cause of these losses is inadequate reactor control. Equilibrium level losses and non-equilibrium losses are primarily dependent upon flattening efficiency and reactivity transient control. Since reactor control improvements appear to be the most fertile field for efforts to reduce production losses, it is recommended that increased emphasis be placed on items such as the Poison Column Control Facility, the poison spline, and the poison displacement cylinder.

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SUMMARY OF REACTOR SECTION PERFORMANCE (cont'd)

To achieve significant production gains, it is suggested that proposed modifications and operational procedures be re-evaluated in the light of the information contained in this document. This type of production loss data may furnish the basis for a greater justification of many proposals than was previously realized.

It is recommended that the procedure of reporting production loss information, as outlined in the reference document, be continued and that information similar to that in Tables I and II be periodically reported by a reactor analysis group. This procedure will furnish a much more accurate and realistic picture of reactor performance and production losses than is now available, and will point out areas where major development efforts should be expended.

DISCUSSION

General

Justifications for new equipment, modifications, and revised operating procedures are currently based on time operating efficiency. The time operating efficiency indicates only how much time the reactor was operating. It does not compare the operating level to the equilibrium level or to the potential level. It does not give a true picture of the production achieved in relation to what would have been obtained at 100 per cent time operating efficiency and maximum power levels currently possible. In short, time operating efficiency alone is lacking as a measure of reactor performance.

To establish a more accurate method of monitoring reactor performance this study was initiated. Basic data were collected from the Reactor Operations Physicists who submitted a report following each break in equilibrium operation. The procedure followed by the physicists in reporting these data is outlined in the reference document. Data reported by the physicists included: 1) the non-equilibrium loss following each break in equilibrium operation, 2) the equilibrium level loss assigned to various causes such as poor flattening, lack of fringe zone reactivity, not operating on limits, hot tubes, and others, 3) the optimum power level, 4) the power level at the time of shutdown from equilibrium, 5) the corrected power level at the time of startup, and 6) the type of startup prior to the non-equilibrium loss.

These basic data were used to develop the method of monitoring reactor performance outlined in this report. The Operations daily reports are the source of actual production figures and the time values. The period covered by this report is from late April through late June, 1956, although the period covered for each reactor is different, being governed by data availability.

DEFINITIONS

In order that the reader may fully understand the pertinent information included in Tables I and II, a short definition of each item is presented in the following paragraphs. To further define these items a simplified illustration is included in Figure I.

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DEFINITIONS (Cont'd)

Non-Equilibrium Loss

The non-equilibrium loss following each break in equilibrium operation was reported by the Area Physicist at each reactor. Non-equilibrium loss is defined as the difference between the actual production and the production that would have been attained if the reactor had started up instantaneously to the previous equilibrium operation power level corrected for changes in inlet temperature. Non-equilibrium losses are present until equilibrium level is reached. Non-equilibrium losses also occur when power level is reduced during operation to control a reactivity cycle, however no reactivity cycles are included in the data contained in this report. Most scrams following startups appear to result from the startup or work accomplished during the outage. All such non-equilibrium scrams or poison outages following a shutdown from equilibrium power level but occurring before equilibrium power level is again attained are included as part of the non-equilibrium loss. This procedure was followed so that a realistic value for the production losses resulting from a shutdown from equilibrium level could be obtained. As a result, the time and production loss during poison outages and non-equilibrium scrams are not included under "days shutdown" or "actual shutdown loss."

The average non-equilibrium loss following cold startups and hot startups are recorded for each reactor in Table II along with the average actual shutdown loss preceeding hot startups. These are averages of the values reported during the time covered by this report. In many cases the number of values from which the averages were obtained were not sufficient to show a precise value. However, the figures listed show the general values of the non-equilibrium losses.

Equilibrium Level Losses

Equilibrium level losses are defined as the difference between the attained power levels and the optimum power level as determined by the area physicist. This equilibrium loss is divided between the various causes or reasons for not attaining the optimum power level. The reasons include poor flattening, lack of fringe zone reactivity, not operating on limits, isolated hot tubes, lack of central zone reactivity, and others. The equilibrium loss included time at non-equilibrium operation as well as at equilibrium operation. In other words, the equilibrium level loss was calculated for the complete operating time between breaks in equilibrium operation. The equilibrium losses are tabulated in Table I along with the percentage of the production potential accounted for by these losses.

Time Period and Time Operating Efficiency

The total number of days on which this report is based is different for each reactor. This time interval was determined by the period covered by the physicists' reports available at the time when the calculations for this report were performed. The shutdown time includes only the time down immediately following a break in equilibrium operation. The time required for non-equilibrium scrams and poison outages is included in "operating days." For this reason the time operating efficiencies tabulated in Table I do not agree with the time operating efficiency as normally defined, however the difference does not exceed one per cent.

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Actual Production

Actual production is the production in megawatt days that was actually obtained. These values were taken from the Operations daily reports.

Actual Shutdown Loss

The actual shutdown loss is defined as the production that would have been made at equilibrium operation if the reactor had not been shutdown. This number was calculated by multiplying the previous equilibrium power level by the number of shutdown days. Here again this figure does not include the actual shutdown loss incurred during poison outages and non-equilibrium scrams.

Shutdown Equilibrium Loss

Shutdown equilibrium loss is the difference between the actual shutdown loss and the production potential during the shutdown.

Production Potential

Production potential is obtained by multiplying the optimum power level by the number of days in the period. The optimum power level was reported by the physicist on each non-equilibrium loss report. This figure is defined by the inlet water temperature, the outlet tube temperature limit, and the optimum number of effective central tubes as specified in a letter to C. W. Botsford from R. E. McGrath dated April 30, 1956, entitled "Establishing Optimum ECT for HAPC Reactors." A per cent of production potential figure is recorded in Table I for each item involving production.

Production Efficiency

Production efficiency is a measure of the actual production as compared to what the actual production would have been if the time operating efficiency had been 100 per cent and if there were no non-equilibrium losses. The production efficiency indicates the loss in production caused by reactor shutdowns and by non-equilibrium operation. This value gives a better indication of losses due to shutdowns than does the time operating efficiency since the production efficiency takes into consideration the non-equilibrium level losses. The production efficiency was calculated for this study by dividing the actual production by the sum of the actual production, the actual shutdown loss, and the non-equilibrium loss.

Reactor Efficiency

Reactor efficiency is the true indication of reactor performance. The term is derived by dividing the actual production by the production potential as defined in a previous paragraph.

Level Efficiency

Level efficiency is a measure of the attainment of optimum reactor power level during operation. It is calculated by dividing the sum of actual production, actual shutdown loss, and non-equilibrium loss by the production potential.

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Operating Efficiency

Operating efficiency is primarily a measure of how rapidly a reactor reaches equilibrium power level subsequent to a shutdown from that level. It indicates the amount of non-equilibrium loss, which is composed primarily of losses during startups. The figure is obtained by dividing the actual production by the sum of the actual production and the non-equilibrium loss.

Accuracy

The accuracy of the information contained in this report was checked by summing the actual production and the several production loss figures and comparing the value obtained with the potential production figure calculated by multiplying the optimum power level by the days in the period. The error was found to be less than 2 per cent, which is within the accuracy of the values reported.

SIGNIFICANCE OF THIS INFORMATION

To illustrate the significance of these various items, each will be discussed separately.

Non-equilibrium losses are those losses occurring when a reactor is not operating at equilibrium power level. This is the production loss because a reactor does not startup immediately to equilibrium power level. The non-equilibrium losses at the 100-K Reactors are unusually high. This is due primarily to a great number of non-equilibrium scrams and the necessarily slow rise to equilibrium level because of reactivity control problems. The 100-DR Reactor has the lowest non-equilibrium loss. This is due primarily to the Poison Column Control Facility which not only affords supplementary control but eliminates the need for a poison outage following cold startups. The total non-equilibrium loss for all reactors was 7.4 per cent of the production potential.

Equilibrium losses are due primarily to inadequate flattening in one form or another. Equilibrium losses are broken down and tabulated under the causes: 1) poor flattening, 2) lack of fringe reactivity, 3) not operating on limits, 4) isolated hot tubes, 5) lack of central zone reactivity and 6) others. These losses make up the difference between the attained equilibrium level and the optimum level as specified by the Area Physicists. The 100-B, KE, and KW Reactors have a high equilibrium loss. This may be due to control problems and reactivity cycling effects at the 100-K Reactors. At any rate, since the total equilibrium loss is 9.1 per cent, better flattening and operation closer to limits should receive increased emphasis.

Actual shutdown loss is the production that would have been made at equilibrium power level during the shutdown. The actual shutdown loss is excessive at 100-D and 100-F Reactors. This is due primarily to the high number of extended outages at these reactors for tube replacement.

The shutdown equilibrium loss is the equilibrium loss which occurs during shutdown. This was separated from the equilibrium loss so that the total loss during shutdown could be measured. This also added to the accuracy of the data since the ideal situation would be to calculate the constantly changing equilibrium loss each day.

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SIGNIFICANCE OF THIS INFORMATION (Cont'd)

Theoretically, the total equilibrium loss is the sum of the equilibrium loss and the shutdown equilibrium loss since this would be the difference between the attained equilibrium power level and the potential power level at 100 per cent time operating efficiency.

The production potential is the production that could be obtained at 100 per cent time operating efficiency at the optimum power level as specified by the individual Area Physicists. The actual production, as obtained from Operations daily reports, divided by the production potential gives the reactor efficiency. This is the true measure of overall performance because it compares the attained production with the plant capacity. Note that the reactor efficiency is the lowest number of the five different efficiencies listed in Table 1. This is because the other efficiencies are measures of specific areas of performance.

The production efficiency is the measure of performance based on the attained equilibrium power level rather than on the optimum power level. This is a measure of the actual shutdown loss and the non-equilibrium loss. Note that this value is lower than the time operating efficiency because it takes into consideration the non-equilibrium losses. Actually, the time operating efficiency recorded in Table 1 is about 1 per cent higher than what would normally be considered time-operating efficiency because time down during poison outages and non-equilibrium scrams were counted as time operating rather than time down. However, the discrepancy between production efficiency and time operating efficiency illustrates that the two values are different although the time operating efficiency has, at times, been used when the value desired was actually production efficiency. It is evident that the time operating efficiency can be used only when the time during which the reactor is operating is desired.

Level efficiency is a measure of how close a reactor approaches the optimum power level during operation. It indicates the amount of equilibrium loss. This is a better measure of equilibrium loss than is the actual value for equilibrium loss because it also includes the shutdown equilibrium loss. Table 1 reveals that, on the average, the equilibrium level is only 88.8 per cent of the optimum level. Better flattening and control is needed at all reactors, specifically the 100-B, D, KE, and KW Reactors where level efficiencies are all below average.

Operating efficiency, not to be confused with time operating efficiency, is primarily a measure of the rapidity with which a reactor reaches equilibrium power level following a shutdown. This is an indication of non-equilibrium losses. The 100-DR Reactor had the highest operating efficiency primarily because of the advantages offered by the Poison Column Control Facility. The 100-KW, KE and F Reactors all had operating efficiencies below average. The average operating efficiency of 89.8 per cent reveals that there is a gain of over 10 per cent to be made by enabling the reactors to operate with fewer shutdowns and to rapidly rise to equilibrium level subsequent to a shutdown. This would involve the elimination of short outages, non-equilibrium scrams, and poison outages. It should be noted here that non-equilibrium losses also include losses due to reduced power level to control reactivity cycles, however this is significant only at the 100-K Reactors.

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SIGNIFICANCE OF THIS INFORMATION (Cont'd)

The information furnished by this method of monitoring reactor performance can be used to justify reactor modifications or used as a basis for evaluating operational problems. This information points out the production gains that could be obtained through the use of facilities such as the Poison Column Control, Operational Charge-Discharge and poison column displacement cylinders. It most certainly shows the importance of reactor control. The non-equilibrium loss coupled with the actual shutdown loss gives an accurate picture of the production losses due to a reactor shutdown. Knowledge of these losses can be used in justifying equipment and operating procedures which would eliminate reactor shutdowns.

Collecting and reporting information such as contained in this report affords a much clearer picture of reactor efficiency and performance, and certainly a clear picture is needed if we are to increase our overall efficiency.

TDD

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Reactor Operations Engineering Unit
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TABLE I

REACTOR PERFORMANCE

<u>Reactor</u>	<u>MWD</u>	<u>100-B</u>		<u>100-C</u>	
		<u>Percent of Prod. Potential</u>		<u>Percent of Prod. Potential</u>	
Non-Equilibrium loss (due to shutdowns)	2168	4.4%		4530	5.7%
Equilibrium loss due to:					
Poor flattening	2051	4.1%		2981	3.8%
Lack of fringe reactivity.	1927	3.9%		-	-
Not operating on limits.	694	1.4%		1340	1.7%
Isolated hot tubes	2379	4.8%		-	-
Lack of central zone reactivity	-	-		-	-
Other	-	-		-	-
Total equilibrium loss	7051	14.4%		4321	5.5%
Actual shutdown loss	5887	11.9%		12448	15.9%
Shutdown equilibrium loss	1094	2.2%		1009	1.3%
Actual production	32870	66.9%		55802	71.4%
Production Potential	49067	100%		78150	100%
Time Operating Efficiency		85.9%			82.9%
Production Efficiency		80.3%			76.6%
Reactor Efficiency		66.9%			71.4%
Level Efficiency		83.3%			93.1%
Operating Efficiency		93.8%			92.4%
Shutdown days		6.50			7.86
Operating days		39.64			38.31
Total days in period		46.14			46.17

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TABLE I (Continued)

REACTOR PERFORMANCE

<u>Reactor</u>	<u>100-D</u>		<u>100-DR</u>	
	<u>MWD</u>	<u>Percent of Prod. Potential</u>	<u>MWD</u>	<u>Percent of Prod. Potential</u>
Non-Equilibrium loss (due to shutdowns)	3033	5.1%	2537	3.6%
Equilibrium loss due to:				
Poor flattening	1271	2.1%	848	1.1%
Lack of fringe reactivity.	646	0.7%	-	-
Not operating on limits.	426	-	-	-
Isolated hot tubes	1652	2.7%	3112	4.3%
Lack of central zone reactivity.	-	-	1082	1.5%
Other	-	-	-	-
Total equilibrium loss	3995	6.7%	5042	7.1%
Actual shutdown loss	23059	38.8%	9154	12.9%
Shutdown equilibrium loss	3305	5.5%	833	1.4%
Actual production	25893	43.6%	53245	75.1%
Production Potential	59287	100%	70812	100%
Time Operating Efficiency	56.4%		86.3%	
Production Efficiency	49.8%		81.9%	
Reactor Efficiency	43.6%		75.1%	
Bevel Efficiency	87.5%		91.6%	
Operating Efficiency	89.5%		95.4%	
Shutdown days	24.11		9.47	
Operating days	31.24		60.02	
Total days in period	55.35		69.49	

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TABLE I (Cont'd)

REACTOR PERFORMANCE

<u>Reactor</u>	<u>100-F</u>		<u>100-H</u>	
	<u>MWD</u>	<u>Percent of Prod. Potential</u>	<u>MWD</u>	<u>Percent of Prod. Potential</u>
Non-Equilibrium loss (due to shutdowns)	2441	5.8%	4649	5.9%
Equilibrium loss due to:				
Poor flattening	720	1.7%	3674	4.7%
Lack of fringe reactivity.	25	-	-	-
Not operating on limits.	145	0.3%	1087	1.3%
Isolated hot tubes	707	1.7%	160	0.2%
Lack of central zone reactivity.	-	-	-	-
Other	-	-	93	0.1%
Total equilibrium loss	1597	3.8%	5014	6.4%
Actual shutdown loss	17951	43.2%	25988	33.2%
Shutdown equilibrium loss	1597	3.8%	2836	3.6%
Actual production	17896	43.1%	40019	51.2%
Production Potential	41484	100%	78109	100%
Time Operating Efficiency	52.2%		63.3%	
Production Efficiency	46.7%		56.6%	
Reactor Efficiency	43.1%		51.2%	
Level Efficiency	92.2%		90.4%	
Operating Efficiency	87.9%		89.5%	
Shutdown days	19.79		22.95	
Operating days	20.50		39.70	
Total days in period	39.29		62.65	

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REACTOR PERFORMANCE

<u>Reactor</u>	<u>100-KE</u>		<u>100-KW</u>	
	<u>MWD</u>	<u>Percent of Prod. Potential</u>	<u>MWD</u>	<u>Percent of Prod. Potential</u>
Non-Equilibrium loss (due to shutdown)	16388	14.1%	8171	8.4%
Equilibrium loss due to:				
Poor flattening	10048	8.6%	6762	6.9%
Lack of fringe reactivity.	1334	1.1%	-	-
Not operating on limits	691	0.5%	4185	4.3%
Isolated hot tubes	-	-	1952	2.0%
Lack of central zone reactivity.	-	-	-	-
Other	2267*	1.9%	-	-
Total equilibrium loss	14340	12.3%	12899	13.3%
Actual shutdown loss	10362	8.9%	11483	11.8%
Shutdown equilibrium loss	1492	1.2%	2169	2.2%
Actual production	75192	64.8%	62248	64.1%
Production Potential	115898	100%	96972	100%
Time Operating Efficiency		89.8%		85.8%
Production Efficiency		73.7%		76.0%
Reactor Efficiency		64.8%		64.1%
Level Efficiency		87.9%		84.3%
Operating Efficiency		82.1%		88.3%
Shutdown days	4.56		5.82	
Operating days	40.47		35.25	
Total days in period	45.03		41.07	

* VSR in Reactor

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TABLE I (Cont'd)

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REACTOR PERFORMANCE

Total - Eight Reactors

<u>Reactor</u>	<u>MWD</u>	<u>Percent of Production Potential</u>
Non-Equilibrium loss (due to shutdowns)	43917	7.4%
Equilibrium loss due to:		
Poor flattening	28355	4.8%
Lack of fringe reactivity	3932	0.6%
Not operating on limits	8568	1.4%
Isolated Hot tubes	9962	1.6%
Lack of central zone reactivity.	1082	0.2%
Other	2360	0.4%
Total equilibrium loss	54239	9.1%
Actual shutdown loss	116332	19.7%
Shutdown equilibrium loss	14335	2.4%
Actual production	363165	61.5%
Production Potential	589779	100%
Time Operating Efficiency - Average	75.3%	
Production Efficiency - Average	67.7%	
Reactor Efficiency - Average	60.0%	
Level Efficiency - Average	88.8%	
Operating Efficiency - Average	89.8%	
Shutdown days	101.06	
Operating days	307.13	
Total days in period	405.19	

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HW-45102

August 29, 1956

TABLE II

AVERAGE NON-EQUILIBRIUM PRODUCTION LOSSES

<u>REACTOR</u>	<u>HOT STARTUP</u>			<u>COLD STARTUP</u>	
	<u>No.</u>	<u>Average Non-Equilibrium Loss - MWD</u>	<u>Actual Average Shutdown Loss - MWD</u>	<u>No.</u>	<u>Average Non-Equilibrium Loss - MWD</u>
B	1	58	17	3	703
C	1	283	15	6	708
D	1	168	28	6	478
DR	2	170	15	6	366
F	3	79	12	4	543
H	7	276	28	6	453
KE	2	2992	56	4	2132
KW	<u>2</u>	1168	40	<u>4</u>	1459
TOTAL	19			39	
AVERAGE		597			889

DECLASSIFIED

FIGURE I

SIMPLIFIED ILLUSTRATION OF REACTOR PRODUCTION LOSSES

END

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