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TITLE: THE EFFECT OF OPERATIONAL CHARGE-DISCHARGE ON THE SLUG RUPTURE LIMIT

AUTHOR: J. R. Young

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THE EFFECT OF OPERATIONAL CHARGE-DISCHARGE ON THE SLUG RUPTURE LIMIT

INTRODUCTION

The installation of operational charge-discharge equipment on the Hanford reactors has been proposed as a means of eliminating the reactor downtime required for charging and discharging the metal in the reactors. Additional benefits such as the minimization of the effects of slug ruptures, improved reactivity control, and improved metal utilization have become apparent during the investigation of the use of the equipment. Since the minimization of the effects of ruptures has been considered only qualitatively in previous justification documents for operational charge-discharge, the purpose of this document is to evaluate quantitatively the effect of such equipment on operation with a slug rupture limit.

The operational charge-discharge equipment currently is visualized as equipment which permits the charging and discharging of reactor fuel elements during operation. Specifically, it consists of new process tube fittings and associated control equipment of such a nature that fuel elements may be charged into the front end of the process tubes and discharged from the rear end of the tubes during full tube flow and power conditions. (9)

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SUMMARY AND CONCLUSIONS

The primary benefits from the installation of operational charge-discharge are: (1) elimination of outage time for charge-discharge of fuel elements, and (2) reduction of the effects of ruptured fuel elements.

Future reactor power levels probably will be limited by the occurrence of ruptured slugs. It is hard to visualize at the present time the fabrication of fuel elements of such quality that the number of ruptures would be small when reactor power levels are increased substantially above forecast levels. As a result, one of the primary benefits resulting from operational charge-discharge appears to be the reduction of the effects of ruptured slugs by permitting more rapid detection and operational discharge of those slugs. The resultant gains are of two major types:

1. Reactor power levels may be increased until the occurrence of ruptures again limits the total production.

2. The discharge concentration of the metal may be increased until the occurrence of ruptures again is limiting the production.

If the reactor power levels are increased as a result of installation of operational charge-discharge and the metal discharge concentration is not changed, the annual gain because of increased production is approximately $13,300,000, and the installation cost of $24,450,000 will be paid off in approximately 1.8 years. If, on the other hand, the metal discharge concentration is increased with no increase in power levels, the annual return, due primarily to reduced metal throughout, is approximately $28,600,000 and the pay-off period is approximately 0.9 years (see tables I, II, and III). Additional benefits on which no economic value are placed at this time because of the many controversial and intangible aspects are:

1. Improved reactivity control.
2. Improved metal utilization if product quality is important.
3. Reactor crash discharge in a very short period of time.
4. A decrease in reactor outages resulting in less reactor thermal shock and less nuclear hazard during reactor start-ups.
5. Better utilization of personnel.
6. Advancement of reactor technology.
7. Installation of new process tube fittings with the following advantages:
   a. Better gas seals on the rear face of the reactor.
   b. Provision for increased process tube expansion at higher tube operating temperatures.
   c. Nozzles designed to facilitate future process tube replacement.
   d. Rear face fittings compatible with pressurization or boiling conditions.
   e. Tube fittings designed to minimize maintenance costs.
8. Reduced personnel exposure due to radiation, particularly as the result of reduced reactor maintenance work and elimination of quickie and shutdown discharges.

If new fuel elements which result in a very minimum of ruptures are available after installation of operational charge-discharge, the primary benefit resulting from installation of operational charge-discharge then becomes a reduction of the reactor outage time required for charge-discharge of the fuel elements. In this case, it must be assumed that the reactor power levels will be increased until there is some

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definite limitation of the power levels. However, since there appears to be no definite limit to reactor power levels if we obtain relatively perfect fuel elements, it has been assumed that the power levels can be increased until they are double those obtainable as a result of the completion of Projects CG-558 and CG-600 at the six old reactors. In this case the installation of operational charge-discharge can be amortized in approximately three years solely on the basis of the reduction of reactor outage time for charge-discharge.

The extra production resulting from operational charge-discharge equipment should also be compared to the capital investment for new reactor construction required to obtain an equivalent production gain. This required capital investment would vary from 48 to 126 million dollars for the three cases mentioned above as compared to $24,450,000 for charge-discharge equipment for the same increase in production. (See Table III.)

DISCUSSION

Future reactor operating conditions

Because the operational charge-discharge equipment probably will not be installed until 1959 or 1960, it is necessary to forecast operating conditions that far in the future in order that the benefits resulting from this installation may be determined. It is anticipated that various improvements in the reactor equipment will be made over the next four to five years so that the reactor power levels will be much higher than at the present or they are anticipated to be in the near future. As a result it has been assumed that the old reactors will be operating at the Project CG-558 design water flow of 71,000 gpm and 120 degrees C maximum outlet temperature (1) (3). No revisions to the reactor water systems are anticipated to permit higher water flows or outlet temperatures. Similarly, the 100-C Reactor is assumed to be operating at a process water flow of 94,500 gpm (2), and the 100-K Reactors are assumed to be operating at a process water flow of 168,000 gpm. (4) It is also assumed that the metal discharge concentration will be 500 MWD per ton because of rupture considerations.

Results of Installation of Operational Charge-Discharge

A. General Types of Gain Realized

1. Reduction of outage time for charge-discharge of fuel elements.

   Installation of operational charge-discharge equipment should eliminate all reactor downtime required for loading fuel elements into the reactor process tubes and discharging those fuel elements which have not ruptured. Equipment should be of such design that all of this work can be performed during reactor operation.

2. Reduction of the effects of ruptures.

   Installation of operational-charge-discharge equipment should reduce appreciably the effects of ruptures as a result of more rapid detection and discharge of the rupture material.

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In addition to the present header sampling system, the proposed operational charge-discharge equipment will provide a separate system for monitoring the effluent water from each tube. This should result in the detection and verification of a ruptured slug and identification of the tube very soon after the rupture occurs. Discharge during operation of a major portion of the ruptured slugs should be possible before they have ruptured so seriously that they are stuck in the tube.

Verification of a rupture should occur sooner than with present equipment. The installation of a second monitoring system would result in two independent signals permitting not only identification of the tube containing the rupture but also earlier confirmation of the existence of the rupture.

The discharge operation is facilitated because discharging the material in the suspected ruptured tube will consist simply of opening the ball valve on the nozzle and flushing the entire tube contents out into the discharge area. It seems reasonable to assume that the ruptured material could be discharged from the tube within a few minutes after verification of the rupture. The tube could then be recharged later after the necessary metal and equipment have been transported to the front nozzle of the tube.

In contrast, at the present time whenever a rupture occurs, it usually is several hours before the ruptured material is removed from the tube. The reactor may continue to operate for a considerable length of time after first indications before the rupture signal repeats often enough to justify action and the reactor shutdown to verify and identify the tube. Throughout this period of time the rupture condition is continually getting worse so that the possibility of a stuck rupture increases.

Since the time required to remove a rupture after it is verified should be reduced from a matter of hours to a few minutes by the installation of operational charge-discharge equipment and since verification should occur sooner, it is assumed that the effects of ruptures on reactor production efficiency will be reduced by 75 per cent.

Advantage may be taken of this benefit by increasing the severity of reactor operation until the occurrence of ruptures is again limiting reactor production. This may be done either by increasing reactor power level, i.e. tube power, or increasing the discharge concentration of the metal. These two possibilities are discussed below:

a. Increased metal discharge concentration.

At the present time, the rupture frequency appears to be dependent on the metal discharge concentration and to increase approximately 2 1/2 times for every 100 MWD/ton increase in the goal exposure of the metal. (5) Since the installation of operational charge-discharge equipment should permit the more rapid detection and discharge of ruptured material, it is anticipated that installation of this equipment will reduce the effects of ruptures by a factor of four. As a result, increasing the discharge concentration of the metal by approximately 150 MWD per ton to 650 MWD per ton should be possible.

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b. Increased reactor power level.

Since the rupture frequency appears to double for every 100 KW increase in reactor tube power, (5) it follows that if we can reduce the effects of ruptures by seventy-five per cent by use of operational charge-discharge equipment, we can then increase the reactor power level to that point at which ruptures again become limiting to total production. In this case, a tube power increase of 200 KW is possible.

3. Required capital investment.

If increased reactor production is desired at the Hanford Operation, two general methods of obtaining this increased production are available. The first would be the construction of new reactors; second would be improvement of the existing reactors to get the same production gain. Consequently, we define the required capital investment as that investment in new reactors necessary in order to obtain the same additional annual production to be realized by improvements to the existing reactors. This cost for new reactors would be from $48 to $126,000,000 as compared to $24,450,000 for charge-discharge equipment. (See Table III)

4. Miscellaneous benefits from operational charge-discharge.

There are several other benefits which can be realized from the installation of operational charge-discharge. However, the effects of many of these benefits are intangible and cannot be calculated with reasonable accuracy because of their nature. Consequently, it was decided to discuss these items and not attempt to determine the associated economic benefits. It should be realized though, that these items will result in additional benefits which should reduce the pay-off period for installation of operational charge-discharge.

a. Improved reactivity control.

Since material may be charged into the reactor process tubes during operation by the use of the operational charge-discharge equipment, it should be possible to adjust the flattening of the reactor to minimize production losses due to non-equilibrium operating conditions. As an example, the overall reactivity of the reactor may be adjusted during start-up so that the maximum possible power level can be realized in a minimum of time. The effects of lack of control rod capacity and operating problems such as hot spots should be minimized, if not eliminated. Most of the gains that can be realized due to reduction of these losses will be realized by use of the poison column control equipment to be installed in the near future. Calculation of the gain that would be realized from operational charge-discharge would be very difficult because the benefits from poison column control cannot be determined accurately at present, but to provide the ability to use any of the reactor tubes for poison or metal charges without moving any equipment cannot help but be of great value.

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b. Improve metal utilization if the product quality is important.

Whenever it is desirable to produce a product of very high quality, such as the current low concentration material, substantial savings in metal cost can be realized if it is possible to discharge the material at the maximum permissible concentration. At the present time such discharge is not possible because the reactors have to operate for several days between metal discharge periods. However, if operational charge-discharge were installed, it would be possible to discharge the metal during operation at exactly the maximum concentration. The reduced metal consumption would result in a substantial cost savings. Since requirements for material of this type at the time operational charge-discharge will be installed is unknown, it is not possible to estimate the associated cost savings.

c. Reactor crash discharge in a very short period of time.

The use of crash discharge has been proposed as a means of minimizing the damage to a reactor in the case of a predictable loss of cooling water or flooding of the reactor area by a disaster at Grand Coulee Dam. At the present time, a crash discharge is not possible in the time permitted before the area would be flooded or the disaster would occur because of the inherently slow methods available for discharging the metal in the reactor. However, if operational charge-discharge were installed, it would be possible to discharge any portion or all of the metal in a reactor within a few minutes so that a successful crash discharge could be accomplished.

d. A decrease in reactor outages resulting in less reactor thermal shock and less hazard to the reactor during startups.

Every time that a reactor is started up there is a thermal shock to the fuel elements and the reactor itself plus a nuclear hazard in that an excessive reactor power level could occur. Installation of operational charge-discharge would reduce the number of reactor outages, particularly for charge-discharge of the fuel elements, so that there should be less thermal shock to the reactor and less possibility of reactor hazards.

e. Better utilization of personnel.

Whenever a reactor shuts down, personnel must be moved immediately to that reactor to accomplish the necessary outage work so that the reactor may be started up as soon as possible. As a result, whenever several reactors are shut down at the same time, personnel requirements are very large and usually cannot be fulfilled without having an excessively large force. Since the installation of operational charge-discharge would reduce the number of reactor outages, the frequency of several reactors being shutdown at the same time would be lowered and personnel requirements during such periods also should be lower. Certainly overtime work requirements would be reduced, and possibly the total force could be reduced.

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f. Advancement of reactor technology.

At the present time, one of the major obstacles to very high power levels for heterogeneous reactors is the amount of time required to charge-discharge the fuel elements during reactor shutdowns. Unless techniques are developed for performing the charge-discharge operation during the operation of reactors, it is possible that heterogeneous reactors may not compete with homogeneous reactors in the future. Installation of operational charge-discharge on a full reactor scale would be a substantial step forward in reactor technology, and if the use of the equipment is successful, this serious obstacle to the use of heterogeneous reactors might be eliminated.

g. Installation at a minimum cost of new process tube fittings compatible with proposed future operations.

In order that operational charge-discharge may be installed on the reactors, a substantial period of reactor downtime is necessary. At that time it would be possible to install at a minimum cost new process tube fittings of advanced design permitting maximum reactor production in the future. As an example, at the present time the reactor power levels are probably limited by the maximum permissible tube expansion at higher tube operating temperatures. New tube fittings could be installed permitting much greater process tube expansion so that much higher reactor operating temperatures would be permissible. Very little additional reactor outage time over that required for the installation of operational charge-discharge would be required.

Other improved tube fittings included are: 1) Better gas seals for the rear face of the reactors, 2) Nozzles designed to facilitate future process tube replacement, and 3) Rear face fittings compatible with pressurization or boiling conditions.

h. Reduced personnel exposure to radiation particularly as a result of reduced reactor maintenance work and elimination of quickie discharges.

The major portion of the radiation exposure received by Reactor Section personnel occurs during reactor outages for reactor maintenance, discharge of ruptured slugs, and charge-discharge. Any reduction in reactor outage work, such as that which would result from the installation of operational charge-discharge, would result in a corresponding reduction of personnel exposure to radiation.

B. Possible increased operating costs resulting from installation of operational charge-discharge.

1. Increased maintenance cost.

Although the installation of operational charge-discharge equipment could increase the complexity of the tube fittings, installation of new fittings of proper design should not result in increased maintenance cost.

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If operational charge-discharge equipment were simply added onto the present process tube nozzle, the result would be more equipment and undoubtedly more maintenance of the reactor, particularly during reactor outages. However, as long as major alterations are to be made to the process tube fittings (9), it would be logical to install new tube fittings which would minimize or eliminate a major portion of the maintenance work presently required on process tube fittings. Typical examples are: 1) relocation of thermocouple wells to accessible positions, 2) quick-connect couplings for fast removal and replacement of rear face equipment, 3) installation of improved gas seals on the reactor process tubes so that leak testing and repair of the seals would no longer be required, and 4) installation of process tube fittings such that the Van Stone flanges are eliminated. In this latter case, repair of Van Stone flanges would no longer be necessary.

2. Increased chemical cost for water treatment.

Increased reactor water plant chemical costs undoubtedly would result from the installation of operational charge-discharge. The increase in reactor operating efficiencies and in water flow rates would result in the delivery of additional process water to the reactor. Since water plant chemical costs are proportional to the amount of water delivered to the reactor, increased chemical costs would result.

Cases of Future Reactor Operations Considered In This Document

A. General

Consideration of future operating conditions indicates that the reactor power levels will be determined primarily by the frequency of metal ruptures. The reactors probably would be operating at the maximum power levels possible without excessive production losses due to removal of metal ruptures. Since at the present time it is not possible to predict quality of the metal being used after the installation of operational charge-discharge equipment, it appears necessary to evaluate the benefit from the operational charge-discharge as if 1) there is a rupture limitation on power levels, and 2) there is no such limitation. If the metal quality is assumed to be good enough that there is no rupture limitation on power levels, then it must be assumed that necessary plant modifications in order to permit higher power levels will be performed. As an example, the reactor effluent systems could be pressurized to permit higher process tube outlet water temperature or the water plants could be modified to permit much higher reactor cooling water flow rates.

In order to evaluate the benefits to be realized from the installation of operational charge-discharge equipment, it is necessary to define six cases of future reactor operation. Cases I and V are base cases representing future reactor operation without operational charge-discharge, with a rupture limitation on power levels and with no rupture limitation on the power levels, respectively. Cases III, IV, and VI represent operation after installation of operational charge-discharge equipment. Case II represents an intermediate or supplementary case necessary in order to determine the reduction in metal costs in Case III as a result of a higher metal discharge concentration. A detailed description of these cases is on the following page. Also, see Tables I and II.

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B. Cases Considered

Case I

Case I represents operation of the reactors with a rupture limitation on power levels and without operational charge-discharge. It is assumed that the reactors are operating at the maximum cooling water flow rate permissible after completion of Project CG-558, and at the maximum tube effluent temperatures permissible without pressurization of the effluent systems. A rupture limitation on power levels is assumed, and consequently the metal discharge concentration is reduced to 500 MWD/ton in order to minimize the effects of ruptures.

Cases II and III

If we install operational charge-discharge on reactors which have a rupture limitation on power level, it is possible to increase the discharge concentration of the metal because the operational charge-discharge equipment reduces the outage time caused by ruptured slugs. In addition there is the benefit of reduced reactor outage time for charge-discharge of the fuel elements.

Operational charge-discharge equipment should permit increasing discharge concentration of the metal from 500 MWD per ton to approximately 650 MWD per ton. Investigations of ruptures in the reactors has shown that the rupture rate increases by a factor of 2.5 for every 100 MWD per ton increase in the discharge concentration of the metal. (5) Since it is assumed that the installation of operational charge-discharge equipment will reduce the effects of ruptures by a factor of four, it follows that the discharge concentration of the metal can be increased by 150 MWD per ton.

Determining the benefits resulting from assuming that the metal discharge concentration can be increased requires the use of a supplemental case. Calculation of the metal required after installation of the operational charge-discharge equipment and increasing the metal concentration and then comparison of this amount of metal to that required in Case I would result in incorrect information concerning the actual reduction in metal requirements. This occurs because the higher reactor operating efficiency after installation of operational charge-discharge results in an increase in metal requirements which would offset part of the reduction resulting from increased metal concentration. Consequently, it is necessary to calculate tons of metal required at the lower (500 MWD per ton) metal discharge concentration but with the higher operating efficiency. The amount of metal obtained as a result of this calculation is then compared to the tons of metal required if the metal discharge concentration is 650 MWD pwer ton. Case II represents this intermediate condition where the reactors are operating at the higher operating efficiency, but are discharging metal at 500 MWD per ton concentration. Case III represents the condition for the reactors operating at the higher operating efficiency and discharging metal at 650 MWD per ton.

Then, in order that the total benefits realized from installation of operational charge-discharge equipment can be determined, the tons of metal used in Case III are compared to the tons of metal used in Case II, but the total reactor production in grams for Case III is compared to the total reactor production in grams in Case I. The productions in grams must be compared rather than in MWD's because the change in the metal concentration at discharge results in a different conversion ratio for the product.

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Case IV

If there is a rupture limitation on reactor power levels, the installation of operational charge-discharge may also permit increasing the reactor power levels. In Case IV we assume that after the operational charge-discharge equipment has been installed, the effects of ruptures has been reduced by a factor of four, and consequently it is possible to raise the power levels until ruptures again limit total production.

Analysis of rupture experience indicates that the frequency of ruptures doubles for every 100-KW increase in the reactor tube power. (5) Since we are assuming that the installation of operational charge-discharge equipment will reduce the effects of ruptures by a factor of four, it is possible to increase reactor tube power by 200 KW.

The two major benefits resulting from installation of operational charge-discharge in Case IV then become (1) increased reactor operating efficiency because of the elimination of downtime for charge-discharge and (2) increased reactor production because of higher permissible reactor power levels. Since no change in metal discharge concentration is assumed in this case, total production is compared to Case I on the basis of MWD's.

Case V

If it is assumed that there is no rupture limitation on reactor power levels, the reactors should then be operating with power levels determined by the next limitation. Since there doesn't appear to be any limitation on the reactor power levels which cannot be relaxed by appropriate feasible reactor or water plant alteration, it has been assumed that the reactor will be operating at twice the power level of Case I. In order that these power levels may be realized, it probably would be necessary to increase the capacity of the water plants or to pressurize the reactor effluent systems to permit higher water temperatures. However, the incentive for performing such alterations to reactors are sufficient that undoubtedly such work would be performed as necessary.

Case V represents the base case without operational charge-discharge and without a rupture limitation. It has been assumed that the metal concentration has been increased to a higher value representative of the optimum operating conditions. Primary effect of this higher metal concentration is to reduce the benefits from installation of operational charge-discharge, since at higher metal discharge concentrations, there would be less time required for charge-discharge of the metal during shutdown, and, consequently, less increase in reactor operating efficiency from installation of operational charge-discharge equipment.

Case VI

Installation of operational charge-discharge equipment on a reactor not limited by ruptures probably would not result in any increase in reactor power level or metal discharge concentration. Consequently, the only major benefits resulting from this installation probably would be the elimination of downtime for charge-discharge. It is this case upon which nearly all of the previous economic analyses have been based, ignoring the more significant rupture slug aspects as represented in Cases I, II, III, and IV.

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APPENDIX

Basic Assumptions

A. General Assumptions

1. All charge-discharge time during shutdown will be eliminated by the use of operational charge-discharge equipment.

2. The basic reactor water flows for Case I are 71,000 gpm at 100-B, D, DR, F, and H Reactors, (1) (3) 94,500 gpm at 100-C Reactor, (2) 168,000 gpm at 100-K Reactor. (4)

3. Maximum reactor cooling water temperature will be 120 C without pressurization of the reactor effluent systems. This corresponds to a bulk cooling water temperature of 97 C.

4. Average reactor inlet cooling water temperature is 12 C.

5. Zirconium tubes will be installed in the reactors starting in 1958. Consequently reactor tube replacement will be a relatively insignificant problem by the time operational charge-discharge is installed.

6. The operational charge-discharge equipment and process tube fittings will be of advanced design so that the reduction in tube fitting maintenance will compensate for any additional maintenance required for operational charge-discharge equipment.

7. The reactor production efficiency changes by a factor of 1.5 times any change in time operating efficiency.

9. Effective central power tubes at the 100 B, D, C, DR, F, and H Reactors is 1500 and at 100-KW and KE Reactors is 2400.

11. If a new reactor were built in order to obtain the production gain resulting from installation of operational charge-discharge equipment, the new reactor would be of 100-K design, costing $80,000,000. This reactor will have the same production as one of the existing 100-K reactors.

12. Metal costs $6.11 per pound at 500 MWD per ton discharge concentration and $6.50 per pound at 650 MWD per ton discharge concentration. (6)

13. The shutdown charge-discharge rates are 330 tubes per day at 100-B, C, D, DR, F, and H and 360 tubes per day at 100-KE-KW.

14. Starting in 1959, the operating efficiency of all reactors without charge-discharge equipment is 80 per cent and the corresponding production efficiency is 70 per cent.

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B. Rupture Limitation on the Power Levels

1. The metal discharge concentration is 500 MWD per ton when operational charge-discharge equipment has not been installed on the reactor.

2. Installation of operational charge-discharge reduces the effects of ruptures by 75 per cent.

3. The rupture frequency at a reactor doubles for every 100 KW increase in tube power. (5)

4. The rupture rate increases by a factor of 2.5 for every 100 MWD per ton increase in the metal discharge concentration. (5)

C. No Rupture Limitation on Reactor Power Level

1. The irradiated metal will be discharged at an optimum economic concentration of 1,000 MWD per ton.

2. The reactor production efficiency decreases 10 per cent for every 50 per cent increase in power level over the Project CG-558 operating condition. This assumes a major effort will be made in order to minimize the decrease in production efficiency as power level is increased. As an example shutdown charge-discharge equipment could be improved.

3. Shutdown charge-discharge rate for all reactors will be 360 tubes per day.

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DESCRIPTION OF CASES

CASE	DESCRIPTION
I	Base Case: No operational charge-discharge, rupture limitations on power levels, Post CG-558 and 600 reactor cooling water flow, 120° maximum outlet water temperature. 500 MWD/ton metal discharge concentration.
II	Case I with operational charge-discharge. Reduced downtime for charge-discharge. (This case used only to calculate the reduced metal consumption in Case III.)
III	Case I with operational charge-discharge. Reduced downtime for charge-discharge. Metal discharge concentration increase to 650 MWD/ton permitted by reduced effect of ruptures.
IV	Case I with operational charge-discharge. Reduced downtime for charge-discharge. Increased reactor power levels permitted by reduced effect of ruptures.
V	Base Case: No operational charge-discharge. No rupture limitation on power levels. Power levels twice that of Case I. 1000 MWD/ton optimum metal discharge concentration.
VI	Case V with operational charge-discharge. Reduced downtime for charge-discharge.

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TABLE II

INSTALLATION OF OPERATIONAL CHARGE-DISCHARGE

(See Table I for description of cases.)

Case	I	II	III	IV	V	VI
Metal Concentration (MWD/ton)	500	500	650	500	1,000	1,000
Power Level						
B, D, DR, F, H	1,630	1,630	1,630	1,920	3,260	3,260
C	2,150	2,150	2,150	2,460	4,300	4,300
KE, KW	3,770	3,770	3,770	4,230	7,540	7,540
Total	17,840	17,840	17,840	20,520	35,680	35,680
Production Efficiency						
B, D, DR, F, H	70%	78.3%	78.3%	78.3%	50%	56.5%
C	70%	81.0%	81.0%	81.0%	50%	58.6%
KE, KW	70%	84.5%	84.5%	84.5%	50%	62.5%
Annual Production						
B, D, DR, F, H	2,082,000	2,329,000	2,329,000	2,744,000	2,97[illegible],000	3,361,000
C	549,000	636,000	636,000	727,000	785,000	920,000
KE, KW	1,926,000	2,326,000	2,326,000	2,609,000	2,752,000	3,440,000
Total MWD						
Total gms.						
Production Gain						
MWD	0	*	734,000	1,523,000	0	1,209,000
Grams	0	*	504,000	*	0	*
Case Compared To	*	*	I	I	*	V.
Tons Metal/yr.						
Total	*	10,582	8,140	*	*	*
Reduction	0	0	2,442	0	0	0
Case Compared To			II			
Metal Cost (10^6)	*	129.3	105.8	*	*	*

* Information not necessary for determination of benefits due to installation of operational charge-discharge.

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TABLE III

Comparison of Cases

SUMMARIZED BENEFITS DUE TO INSTALLATION OF OPERATIONAL CHARGE-DISCHARGE

Cases Compared	I-III	I-IV	V-VI
Rupture Limitation on Power Level	yes	yes	no
Primary Benefits			
Elimination of Outage Time for Charge-Discharge	$6,685,000	$6,685,000	$7,705,000
Increased Power Level	--	$7,185,000	--
Increased Metal Discharge Concentration.	$22,066,000*	--	--
Gross Annual Gain	$28,751,000	$13,870,000	$7,705,000
Increased Annual Chemical Cost	163,000	457,000	203,000
Net Annual Gain	$28,588,000	$13,413,000	$7,502,000
Installation Cost	$24,450,000	$24,450,000	$24,450,000
Pay-Off Period (Years)	0.85	1.8	3.3
Production Gain:			
Percent	13	13	19
Equivalent 100-K Reactors	0.60	1.58	0.88
Equivalent Capital Cost	$48,000,000	$126,000,000	$70,000,000

* Savings of metal cost reduced by lower conversion ratio.

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