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CHARGE-DISCHARGE DURING PILE OPERATION

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I. INTRODUCTION

This document presents a general analysis of charge-discharge during pile operation. It is not a detailed technical, operational, economic, or political analysis, but rather an attempt to cover the subject with a broader viewpoint than is usually presented in the many detailed reports which have been written in the past five years. This letter is occasioned at this time because efforts are in progress to implement plans for proceeding with the expenditure of substantial amounts of money in order to demonstrate that the system, as developed, will allow the attainment of certain desirable objectives.

II. CONCLUSIONS

1. Economics

An analysis of the potential economic gains, assuming certain conditions of operation of the equipment, shows that the installation of charge-discharge on the C Pile under a continuing low exposure program would give an attractive payoff period. These potential gains would be severely reduced or eliminated at present high goal exposures.

2. Additional Development and Testing

There are unsolved problems and uncertainties regarding the reliability of the proposed installation and effects on operation that detract from the potential gains.

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Clarification of some of the important problems should be attempted with separate pile tests such as the effects of rifling and cocking on rupture characteristics.

3. Timing

The five tube facility which is presently installed can be used to obtain information on general operability of the equipment, maintenance problems associated with its use, the effects of slug cocking and rifling, and possible malfunction of the equipment. It is believed that design of the full pile installation should be deferred until extensive information on the above items has been obtained.

The initiation of final design and procurement of equipment for a full pile installation is believed to be premature. Consideration of the risks and unsolved problems in relation to the potential gains leads to the conclusion that the development of this system has not been advanced enough to justify the installation on a full pile basis.

4. Risk versus Gain

It is believed at the present time, in view of the many unknowns associated with this program, that the overall risk is too great and the expected returns too uncertain to justify the relatively large expenditures involved in a full pile installation.

III. BACKGROUND

1. Historical

The first serious consideration given to charging metal into the Hanford piles was operation was instigated by the former Design and Construction Division as part of the "G" pile program.⁽¹⁾

The "G" pile was to have been an 800 MW installation and it was estimated that discharge during operation would increase the plutonium production 6 to 10 per cent. It was originally planned to combine continuous charge-discharge with segmented discharge to realize the optimum benefits. It was later shown that under the customer contaminant requirements in effect at that time segmented discharge contributed very little, so it was dropped from consideration. Also under development at that time was the so-called "Postum" machine which was intended to be used for charging request material into tubes running crosswise in the pile.

The preliminary study was very optimistic about the probable success of such a system. This resulted from the assumption that if only standard components such as cylinders, cams, gears, etc. were used there would be no parts to be proved and hence little chance of failure. However, as pointed out in Sections 3 and 4, other unforeseen difficulties arose which rendered the proposed system inoperable.

A working committee on charging methods, with one member from the Design, Technical, and Manufacturing Divisions was established in early 1950 to review the developments then underway. Their conclusions⁽⁴⁾ indicated, among other things, that it would be necessary to provide lubrication during charging to prevent slug and tube damage and that operation of the charging machine must not introduce the possibility of losing water from the tube.

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2. Basic Advantages and Disadvantages

The following basic gains would be expected to result from the installation of a charge-discharge system:

- a. Downtime now required for charging and the attendant startup loss would be largely eliminated.
- b. A higher percentage of ruptured slugs would be discharged before they became stuck.
- c. Uranium utilization would be improved because discharge could be made at a desired exposure.
- d. Operation would be possible with more tubes closer to temperature limits, because occasional abnormal limiting tubes could be discharged.
- e. Some operational convenience would be obtained because major reactivity cycling would be reduced.

Tending to counteract these gains, certain direct losses are expected to be incurred. These include:

- a. Additional maintenance time for the charge-discharge system.
- b. Extra downtime for tube and thermocouple replacement, for repair of pigtail and gas leaks, and other similar work.
- c. Some increase in the number of scrams because of the complexity of its operation.

3. Development Work and Results

Two charge-discharge systems were tested for Design. The first, consisting of a charging machine and a discharging machine and known as the "pressurized" system, was for charging regular metal into the process tubes. The second system was known as the "postum" system and was to be used for charging special non-heat producing materials into tubes which were to run crosswise in the pile. This system consisted of a charging machine and a piping system into which the slugs would be discharged.

It was soon apparent that the pressurized charging and discharging machines would not operate satisfactorily under pile conditions. Although the pressurized charging machine worked, after difficulties due to design and fabrication errors were corrected, it was quite cumbersome and operation of the rams increased or decreased the process tube pressure by as much as 50 pounds per square inch. The pressurized discharge machine proved to be inoperable. Its operation, which inherently maintained the column intact at all times, required that the newly charged column or slugs be backseated to effect the tube closure and this proved impossible to accomplish. It was shown that forces up to 7000 pounds would not backseat the charge because cocking and buckling of the slug column caused the slugs to bind.

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Testing of the so-called "postum" system indicated that the charging machine was quite satisfactory but that the equipment at the discharge end was unworkable. The discharge assembly was designed so that the slugs were to be discharged directly into a vertical riser. The force exerted by full flow was sufficient to cause the slugs to jam in the riser when attempting to discharge.

It is estimated that the funds expended on this development program were on the order of \$300,000.

4. Unsolved Problems

The development work was discontinued because of a combination of reasons. The equipment being tested at that time could not be made to function properly without considerable re-design, almost to the extent of completely new concepts of operation. Important problems such as slug cocking and column buckling were discovered and considered quite serious and devoid of simple solution.

Objections had also been raised regarding other phases of the operation. While some of these problems were relatively minor, and have since been solved or eliminated from consideration, they are listed here since they did influence the thinking and decisions made at that time:

- a. The dumping of large amounts of potentially contaminated water directly into the basin was considered an undesirable practice because of possible contamination buildup in scum, etc.
- b. Similarly, spraying large amounts of contaminated water on the rear face piping and walls was undesirable.
- c. The possibility of losing a slug somewhere on the rear face in an inaccessible location was cause for much concern.
- d. The equipment being developed to discharge a slug with minimum water spillage required remote indexing and positioning, something that is always suspect of derangement and malfunction.
- e. Serious concern was expressed with regard to the problems involved if a slug were to become stuck at the end of the nozzle through which it was being discharged.

When examined in light of these problems and the feasibility of solutions for them, an economic analysis of this method of operation applied to the high exposure material being produced at that time did not reveal a strong justification for continuing the program. The final report⁽²³⁾ on this program concluded "there is no justification at the present time to continue development work on a charge-discharge system if the basic premises used in this document can be accepted as correct. A rise in the number of ruptured slugs or a change in exposure rates could necessitate an economic re-evaluation of the program".

The general interpretation of the test results was that the economic incentives would have to be very strong and the gains clear-cut and obvious to warrant reactivation of the program in its entirety. Various phases of the program were continued however, with the principal emphasis being directed toward the more basic slug behavior and hydraulic problems.

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5. Manufacturing Development

The charging of poison for control purposes was first suggested in 1951 by the Manufacturing Department⁽⁷⁾. This system consists of a pressure-lock charging cylinder and valves on the front and rear of the process tube. Poison is removed by opening the rear valve remotely and flushing out the poison material. The poison is charged through a pressure lock and valve on the front nozzle with the water flow flushing the pieces down the tube. Manufacturing gives the following as the bases for this system:⁽¹²⁾

- a. Control of local hot spots.
- b. Poison adjustment to permit optimum rod configuration.
- c. Discharge of temporary poison without shutting down the pile.
- d. Discharge of regular poison to extend scram recovery time and reduce minimum downtime.
- e. Faster rise to full power level.

The modifications which have been made to the system to permit uranium charging and discharging consist of the following:

The rear nozzle was equipped with two lines, one for water sampling and the other for a continuous pressure monitor. The front nozzle was equipped with a special pressure tap in the ball valve adaptor. The throat pressure tap of the venturi was transmitted through the normal Panellit sensing line. Mounted on a wall in the control room was a differential Mercoid which formed the auxiliary safety circuit tube flow monitor and this instrument was pressurized through the Panellit manifolds. In this manner, the tube inlet and throat pressures were continuously monitored on separate Heise gages. A Panellit gage was installed on the far side of the reactor to monitor rear nozzle pressure but was not connected to the safety circuit.

The poison charging machine was modified by adding an auxiliary flow line and a pressure gage to the front end of the cylinder.

IV. CURRENT STATUS

1. Poison Column System

In the summer of 1952, under PT 105-1-MR⁽¹²⁾, a one tube system was installed on B Pile and was used on three occasions to charge a 45 slug lead-cadmium poison column within one hour after reactor startup and to discharge the poison during operation at power levels of 250, 300 and 414 MW.

PT 105-4-MR⁽¹⁷⁾ was initiated to install poison control nozzles on 18 process tubes at B Pile. By September 30, 1953 a total of 94 individual charge or discharge operations for poison startups or flattening adjustments had been made. Process reported a production saving of 1222 megawatt days for this period. In October of 1953 the

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facility was used on four startups with a claimed production saving of approximately 1048 megawatt days. In November two flattening columns were discharged, three temporary poison columns charged and two uranium columns discharged, a saving of approximately 410 megawatt days. In December savings of 715 megawatt days were reported. At this time the equipment was turned over to Operations for maintenance responsibility although operation of the facility continued under PT 105-4-MR. Several tubes were reverted to plutonium production to gain needed reactivity. No savings were claimed for January. The equipment was used whenever possible. During April 1954, 15 tubes were moved to DR Pile to alleviate the critical need for supplementary control and because of the diminishing value at B Pile as a result of the use of 10-66 material for flattening. Three tubes remained at B for uranium charge-discharge study. From July 2, 1953 until April 11, 1954 production increases of 5147 megawatt days were reported.

Gains which can be attributed to the use of the equipment are no longer reported month by month; however, the equipment has been used routinely to date.

2. Uranium Charge-Discharge

PT 105-4-MR, Supplements A and B^(20,25) were initiated to demonstrate the feasibility of routine charge-discharge of uranium slugs during operation using poison column control equipment. Supplement B authorized the experimental charge and discharge of one tube during operation and this was successfully performed on June 3, 1954, using tube 2255-B. Average local tube power level was 315 KW. Extra cooling was provided by the use of a central zone orifice, and the flow was continuously monitored by the pressure differential between venturi throat and tube inlet. The tube was removed from the safety circuit during discharge and this bypass was removed — the rear dummies were charged. During slug charging, a Mercoid differential pressure switch was in the safety circuit, set to trip at approximately 7 gpm higher than the flow required to prevent boiling. This operation was performed without incident, tube did not rupture and was discharged at 200 MWD/T exposure.

Under PT 105-8-MR,⁽³⁰⁾ six more tubes were successfully discharged and recharged with uranium slugs during operation using the modified poison column control equipment. Power ranged from 315 KW/tube to 660 KW/tube, the last four tubes being charged in the highest power range available at B Pile. Three charges, placed in 315, 405 and 650 KW tubes have been discharged at 200 MWD/T and inspected. No difference from normally charged slugs was found. The remaining four tubes were charged in approximately 650 KW tubes and are now operating up to approximately 800 KW/tube with concentrations up to 800 MWD/T. Each tube was charged with modified poison column control equipment, and tube flow and temperature were continuously monitored. Flow meter pressure was measured across the exit cone of the inlet venturi. The safety circuit was tied in by means of a Mercoid differential pressure switch set to trip at approximately 3 gpm before boiling.

On March 7, 1955, the discharged metal was examined from three of these tubes which were run to a level four times C reactor normal exposure. There was no evidence of a serious condition.

Discharging high power central zone tubes requires close control by control rods during equilibrium operation to prevent severe upset of the heat distribution — The size of this effect depends on concentration and tube power; however, during these tests the maximum did not exceed ten inhours.

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3. Five Tube Prototype

The current program for continual charge-discharge calls for two demonstration steps before application to all piles. The first step consists of the installation of prototype equipment on five tubes at C Pile. This installation was authorized by PT 105-8-MR, Supplement A.⁽³⁴⁾ The equipment was designed, fabricated and installed under Project CG-609. Before installation on the pile, it was assembled for mock-up testing and demonstrations of its operation were given to interested personnel. The equipment was installed on C Pile on 3-24-55. The system is believed to be adequately safe from considerations of pile cooling.

One of the purposes of this installation is to demonstrate the feasibility of operating personnel routinely charging uranium during operation. A further purpose is to provide functional testing of equipment and procedures believed to be suitable for routine operation. The equipment incorporated certain design changes which past experience with experimental equipment has shown to be desirable. This investigation of the mechanical and operational functioning of prototype equipment will give some insight to the maintenance requirements of the equipment and to the number of spurious shutdowns which might be expected to result from the installation of this equipment on a complete pile.

Another principal purpose of the five tube installation at C Pile is to investigate the possible effects of high tube powers on material which has been charged during operation. It is expected that the effects of such things as slug cocking, slug damage as a result of impact during charging, and inadequate slug cooling during charging would become more apparent with increasing tube power.

The Manufacturing Department anticipates⁽³⁵⁾ that this installation and test program will demonstrate that these effects are either not apparent or not damaging at the highest tube powers at C Pile.

4. Project Preparation

The second step in the current program calls for a full pile installation of continual charge-discharge equipment at C Pile. Funds were provided for this installation in the amount of \$800,000 in the Construction Budget for Fiscal Year 1955. It was originally intended that the techniques and equipment for this conversion would be fully demonstrated by the five tube installation discussed above. However, because of the delay in getting the program underway, data from the five tube installation will not be available for the preliminary full pile design. The full pile installation is scheduled for FY 1956.

Detailed design of the installation will take place during the equipment procurement period.

V. CONSIDERATIONS

A. Economics

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1. Expected Net Gains*

The net gain to be realized from the installation of charge-discharge equipment at C Pile has been estimated. At a goal exposure of 200 MWD/T it has been estimated that approximately 45,000 MWD/year would be the net gain exclusive of better metal utilization. Using a value of \$15/MWD irradiation cost this is equivalent to a saving of \$675,000. To this is added a value for better metal utilization estimated at \$380,000 per year. The total net gain is then about \$1,000,000 per year. The following assumptions were used as the bases for the estimate for the increased MWD/year.

- a. Ruptures - It was assumed that 85 per cent of all ruptures presently require the minimum shutdown equivalent to 31 hours of full power production. With the charge-discharge system it was estimated that only 20 per cent of the ruptures would require minimum shutdowns. It has been estimated that at low g/t 10 regular production metal ruptures will occur per year.
- b. Power Level - Power level was assumed to be 1600 MW.
- c. Normal Maintenance - It was assumed that 300 hours forced maintenance time per year is required. It has been assumed that general maintenance will be performed during the time the pile is down for rupture removal.
- d. Extra Maintenance Time Associated with Charge-Discharge -
 1. Maintenance of the C-D system is estimated to require 60 hrs/yr.
 2. It was assumed that 200 tubes per year will be replaced and that the charge-discharge installation will require an additional 30 minutes per tube. While the number of tubes replaced per year is now a minor item, power increases will be made toward the economic optimum of 400 - 500 tube replacements per year.
 3. It was estimated that regular maintenance will require 40 items such as replacement of thermocouples, repair of pigtail and gas leaks, etc. per year. It was assumed that 30 minutes extra per item would be required because of the complexity of removing and replacing rear-face charge-discharge equipment.
- e. Unavoidable Shutdowns - The proposed charge-discharge assembly will have four differential pressure Mercoid gages, a Meletron sensing alarm, and a Brown temperature indicator, alarm, and scram system. Thus, the number of scram instruments for the tube flow system would be increased from 1 to 6. However, for the five tubes requested under PT 105-8-MK the number of gages would be increased from 5 to 11, while for a whole pile it would only be increased from 2002 to 2008.

*A more valid method of calculating net gains would be to carry out the following steps: (1) Calculate gms. product made because of C-D, (2) Calculate total cost per gm. of making the product, taking into account (a) charges for metal and fabrication, (b) increased variable separation operating charges, (c) increased variable pile operating charges, (d) increased variable 234-5 charges, and (3) Compare the cost of making this product with the plant average. This method is relatively complex and is believed that the approximate method used is sufficient for the purposes of this.

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These gages are equipped to ring an alarm at some point before the scram trip point is reached. This increased instrumentation always increases the chance of an unnecessary scram and the use of a relay connected to each Pamellit (2000 total) is expected to cause extra scrams. It is estimated that at least one extra scram per month will occur.

- f. Operation Closer to Existing Temperature Limits by Discharge of Abnormal Limiting Tubes - It was assumed that this gain would be 0.5 per cent of the total production.

In calculating metal savings gain the following assumptions were used:

- a. Two per cent reduction in uranium input.
- b. Five hundred thousand MWD/year total production.
- c. \$/# uranium = \$3.25 + \$0.003 (MWD/T).

2. Effect of Increased Rupture Rate

It is not possible at this time to evaluate whether C-D will increase the rupture rate. One can estimate the increase in rupture rate required before C-D gains are cancelled. This factor of increase can be estimated to be about 18 by the following means:

- a. $\text{MWD/year equivalent to metal savings}^* = \frac{\$380,000/\text{year}}{15 \text{ \$/MWD}}$
25,000 MWD/year
- b. Total MWD gain for C-D = 25,000 + 45,000 = 70,000 MWD/year.
- c. Number of additional (in addition to 2 assumed normal) stuck ruptures caused by C-D for breakeven.
$$= \frac{70,000 \text{ MWD/year}}{1600 \text{ MW } (31/24) \text{ days/stuck rupture}} = 34$$
- d. Assuming that C-D would prevent 80 per cent of ruptures from being stuck this means 170 additional ruptures/year or a total of 180 ruptures/year.
- e. The factor of increase is $180/10 = 18$.

If the present rupture rate at C is 0.0005 this would result in a rupture rate of 0.009 for breakeven.

* This step is probably not accurate in detail, however, it is true that credit should be given for metal savings in the estimation and this convenient method is used.

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3. Goal Exposure Effects

If it were desired to convert C Pile to high exposure, the gains from C-D would be lessened because:

- a. Little or no incentive for precise goal discharge is present.
- b. The production gains because of saved C-D time is lessened by large factors depending on the number of ruptures assumed per year.

4. Uncertainty of the Low g/t Program

Hanford experience from the beginning of the low g/t program has shown it to be extremely unstable as to the commitments that the AEC expects per year from Hanford. One cause for instability of the program arises when the AEC changes total low g/t requirements. Another source of this uncertainty apparently arises from the fact that although the AEC presently requires a rather well defined total low g/t production each year, this production is split between Hanford and Savannah River. As far as it is now known, AEC plans for Savannah River include large thorium irradiations with perhaps large irradiations of low g/t but with little or no high exposure product. As difficulties or changes from other sources in the Savannah program arise these are reflected quickly and drastically by changed commitments to come from Hanford.

Installation of charge-discharge during operation equipment on a pile commits that pile to a low exposure material during the payoff period for the installation of the equipment, if the payoff period is to be minimized. With such a rapidly varying program the inflexibility of committing a particular pile or piles to one type of product until the payoff is reached must be considered.

B. Risks and Unsolved Problems

1. Slug Effects

During the testing of the charge-discharge equipment, the phenomena of slug buckling and cocking were discovered. It was found that any time the slugs were allowed to wash down the tube or were not charged in perfect alignment varying degrees of cocking resulted. While Process⁽³⁸⁾ reported, on the basis of seven tubes charged during operation, that there was no evidence of slug cocking, J.P. Cooke reported⁽¹⁶⁾ that X-ray studies in the laboratory showed that any time slugs are allowed to rifle down the tube, 30 to 50 per cent of the slugs are cocked. Thus it is felt that the incidence of cocked slugs will be high and whether this will be a problem is yet to be established. The "Tru-line" slugs were developed to eliminate cocking and preliminary test results were promising. It was concluded⁽¹⁸⁾ that they would appreciably reduce cocking resulting from washing slugs down the tube, but that additional evaluation was necessary since some damage was observed when the slugs were misaligned.

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The effect of slug cocking on process tube flow rates was also investigated. The slugs were held in the tube in such a fashion that the maximum possible amount of cocking existed. The flow through a C Pile tube having 400 psig header pressure and a 0.318 inch orifice would be reduced on the order of 8 per cent. The flow through a standard annulus tube having a 0.285 inch orifice would be decreased about 9 per cent.

One hundred slugs were charged and discharged from the process tube at normal flow rates. The scratches on these slugs were measured by the microscopic depth-of-focus method and compared to a group of normally charged slugs. The comparison shows that while the number of scratches on a slug charged at full flow conditions is far greater than a normally charged slug, on the basis of this limited number, the depth of the scratches does not appear to be so severe as to be a limiting factor.

A production test was run to determine the maximum axial load exerted by the slug column. This load was found to be 535 pounds and shows by comparison to earlier out-of-pile deflection tests that column bowing severe enough to raise portions of the slug column off the ribs of the process tube far enough to touch the top of the tube can occur during pile operation.

Sufficient information is not available from which definite conclusions on this subject may be drawn.

2. Equipment Reliability

The increased complexity of various systems and operations connected with instituting charge-discharge during operation necessarily will cause some lost production as a result of unnecessary shutdowns and increased pile maintenance time. At the present time there has not been enough experience with this operation and equipment to estimate accurately the extent of these losses.

Examples of such possible losses can be visualized. For instance, the necessity for bypassing all or part of the present tube flow monitoring system and substituting additional safety mechanisms during tube charging probably will cause an increase in the number of spurious pile scrams, either as a result of faulty equipment or faulty operation.

Some lost production will result from the necessary maintenance on the special charge-discharge equipment, and this equipment also will impede and slow other pile maintenance work such as tube removal, temperature monitor element replacement, and stuck charge removal.

Some additional risk of coolant flow stoppage to a slug column results from the possible misuse of the equipment and the general higher level of work activity on the front face during pile operation. At present tube powers, such an event would initiate slug jacket melting even though a pile scram were initiated immediately.

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3. Incompatibility with Other Systems

With the high tube powers which will exist in the near future at C Pile, it is expected that the slugs will be operating in the beta phase. The transformation tube power (for central slugs) is 1130 to 1180 kilowatts. It is not known whether operation over this tube power and at 200 to 300 MWD/T exposure will result in an intolerable rupture rate. Should the rate be intolerable, improved slugs will be required. For the purpose of example, it is assumed that cored slugs would be satisfactory in the beta phase. The extra cost of cored slugs (estimated at \$2.00/slug) makes production of low g/t product economically unattractive at C Pile. A better scheme might be to produce the low g/t product at the old piles with solid slugs, or at any pile in which the beta phase would not be attained, and to run cored slugs in the C Pile to as high an exposure as is economically desirable under considerations of slug rupture and any other applicable limits or factors. Addition of charge-discharge to C Pile tends to commit the pile to low g/t during the pay-off period and therefore reduces plant flexibility.

The pressurization of the rear crossheaders may have an adverse effect on this proposed system. These headers may be pressurized to perhaps 70 psig giving an allowable outlet temperature of 145 C. Before discharging a tube operating at this temperature it may be necessary to lower the outlet temperature to 95 C by increasing the water flow through the tube. This operation may present complications to the normal operation of the surrounding tubes.

As segmental discharge is presently being developed, charge-discharge during operation and segmental discharge are not compatible. Depending on the actual speed of the operation, savings for 200 MWD/T material might be appreciable and could possibly exceed those for charge-discharge during operation.

C. Indirect Considerations

1. Power Pile Development

The argument has been advanced that the installation of charge-discharge during operation equipment is particularly important because of the desirability of this type of system on a power pile. No power pile is being designed to operate under the conditions which we currently have or anticipate in the Hanford piles. This proposed installation would contribute little to the technology of automatically charging and discharging a power producing pile.

2. Marginal Aspects

The installation of a charge-discharge system has been the topic of much discussion and expression of opinion, and it is recognized that there are some political ramifications to the problem. This phase of the subject can not be adequately evaluated.

3. Psychological Objections

Many people who have considerable experience in development work and pile operation believe that the proposed system is inherently less safe than the present

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charging system and should not be considered when the gains are relatively small. Although steps may be taken to prevent all predictable failures, the addition of a complicated operating procedure will introduce an additional degree of risk which cannot be predicted. The use of judgement is necessary to evaluate this factor.

VI. ACKNOWLEDGEMENT

This document is a compilation of information contained in many detailed reports. Particular sections of the document are referenced to their source material included in the attached general list of documents on the subject.

The bulk of the material was obtained by personal communication from the following members of the Pile Technology Section: W.K. Alexander, M.W. Carbon, J.P. Cooke, D.J. Foley, L.W. Lang, W.J. Morris, J.F. Music, G.J. Rogers, R.J. Shields, and H.G. The author wishes to express his appreciation of their assistance.

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