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TITLE

CONTINUOUS EFFLUENT WATER HIGH TEMPERATURE MONITOR FOR B,C, D, E, F, AND H PIPES

AUTHOR

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CONTINUOUS EFFLUENT WATER HIGH TEMPERATURE MONITOR
FOR B.C.D.D.R.F. AND H PILES
by R.S. Paul and D.E. Stephens

INTRODUCTION

Continuous monitoring of the pile outlet water temperature may offer definite advantages from both the operating efficiency and pile safety points of view. The temperature data could be continuously displayed which would 1) provide Operators with the kind of information required to operate efficiently while remaining within specified tube outlet water temperature limits, and 2) permit tube outlet water temperatures to be continuously in the scram circuit, thus contributing to safety of operations.

The most positive protection against flow instability due to localized power surges would be given by a safety system which continuously monitors the effluent

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from each of the process tubes for temperatures above safe maximums. Such a system would need 2004 controllers and would be relatively expensive and time consuming to install using existing methods of proved industrial instrumentation. However, if the temperature generation of adjacent tubes is closely related, there is a possibility of using a system of fewer controllers in which each "controller tube" supervises a number of adjacent tubes. This report outlines a study undertaken to show whether or not such a system might prove feasible. It contains a comparison of two suggested systems, one using one controller monitoring the outlet water temperature for each twenty-five process tubes and another using one controller for each nine process tubes. The detailed justification for installing any system is not considered in this report.

The bulk of the data in this report were collected and initially analyzed by D. E. Stephens. After his termination from HAPO, the data analyses were completed and this report prepared by R. S. Paul.

SUMMARY

The feasibility of providing a localized temperature monitor for B, C, D, DR, F and H piles is considered. This would use K pile type temperature controllers to monitor the exit coolant temperature of one control tube in each cell of 9 or 25 tubes. The expected performance is predicted by a study of tube temperature data from two periods of transient behaviour. Three types of systems are compared with the assumption that a ten degree uncertainty in the temperature of the hottest tubes could be tolerated during transient conditions.

Cost estimates, based upon costs of the temperature monitoring equipment for the K-piles and the costs of the recent thermocouple replacement in the older piles, show that, exclusive of indirect project charges, a safety system utilizing one controller for each nine tubes would cost approximately \$47,000 per area and require five days of pile down time for installation. The system utilizing one controller for each twenty five tubes would cost approximately \$21,000 per area, and would require three days of pile down time.

It is concluded from these data that:

- 1) A reduced coverage temperature controller system can provide adequate trip-before-flow instability protection under most foreseeable conditions.
- 2) The relative low cost and simplicity of a reduced coverage system can insure much sooner installation and protection than could be expected for an every-tube monitor.
- 3) A more expensive 3x3 cell system (one tube in nine monitored) shows little advantage in assured protection over a 5x5 cell system (one tube in twenty-five monitored).
- 4) A few extra controllers should be provided for additional coverage of known critical locations.

5) Further data, which are expected from a current Development Test⁽¹⁾, should be available to fully specify optimum operating procedures for a reduced coverage controller system.

In addition to the safety system application the K pile type of temperature monitor could readily be adapted to yield a continuous display of outlet tube temperatures. Such a display would assist Operations in efficiently operating while remaining within tube outlet temperature limits.

DISCUSSION

The concept of monitoring the effluent temperatures of only a relatively few selected "control tubes" rather than every process tube is attractive providing:

- 1) It insures, with confidence, a high degree of protection against flow instability being initiated in the active zone of the process tube by excess power generation in the tube.

- 2) The greatly reduced cost and reduced complexity compared to a full pile system can significantly shorten the time before installation and provide pile protection at a much earlier date.

- 3) The relative instrumentation simplicity reduces system operating costs and time and promotes improved maintenance.

This report discusses an instrument system based on components which have already been demonstrated and which allow for a good cost estimate. Temperature data are analyzed to indicate the performance characteristics of several possible system arrangements and to show those areas of operation where more complete information is desired.

A. Instrumentation

The controllers suggested for this system basically parallel the design of the controllers being employed in the K-pile temperature monitors. Each controller would consist primarily of a resistance bridge whose null indication would operate a relay in the safety circuit of the pile. Resistance bulb thermometers could be used as the primary elements, and would constitute the unknown resistance leg of the bridge. The opposing, or measuring arm of the bridge would consist of a variable resistance calibrated in terms of bulb temperature, and would lie in the range of trip temperatures. The null sensing device of the bridge could be either a magnetic amplifier, or a meter; either device would operate a relay in the safety circuit when the bulb temperature reached the trip limit set on the controller.

The resistance bulbs would be located in pigtails specially modified as those used at H-pile for Development Test No. 105-564-A (see Figure 1). The resistance bulbs would not replace the existing thermocouples of the regular pile temperature monitor; the operation of the existing pile temperature monitor would not be affected by the installation of this control system.

(1) Paul, R.S. - HW-34367, Development Test No. 105-595-A - Test of a Cell System Temperature Monitor

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TEMPERATURE MONITOR
PROTOTYPE TEST

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The controllers would be located in the control room, or a convenient adjacent location. A graphic panel display in the control room would feature all of the systems annunciation and control features. A controller initiating a scram would be identified by coordinate lights. Reset and test functions would be handled from the panel, and those controller tubes approaching trip limits would be indicated either on the controller or the graphic panel.

It appears possible that some high tube temperatures may exist at times wherein supplementary control, in addition to that provided by the permanent set, might be needed. Provision is allowed for this by including ten controllers which could operate on servo-null principles as do the Brown recorders on the pile temperature Monitor. These controllers could then operate from the thermocouple signals available at the pile temperature monitor jack panel, and could be plugged in at the discretion of the operator. A simple revision to the existing temperature monitor scanning equipment would allow these controllers to be by-passed whenever the temperature monitor is scanning a point plugged in on the jack board. Figure 2 is a schematic presentation of the proposed safety system.

In general, the use of a resistance bridge is a sound step free from argument. However, the choice of components for the null measuring device in the bridge is still open. Extensive experience with the meter operated relay is becoming available at the K piles. Some limited work has been done with magnetic amplifiers in this field as they may have more inherent reliability but at a possible higher cost. These component options are being given further study by Physics Development, Process Engineering, and Design Engineering.

The minimum number of controllers required to provide a desired degree of pile safety is dependent upon the extent of transient temperature correlation among neighboring tubes and the geometric arrangement of the controllers. This study compares the performance of two possible systems. One having a controller for each twenty-five tubes and the other having a controller for each nine tubes as shown in Figures 3 and 4. The positions were picked without regard to the pile loading in the data analyzed and were arbitrarily chosen as feasible distributions. It is assumed that the pile flattening pattern and metal irradiation needs could be arranged to allow for permanent location of a controller on one tube in each cell. The 5x5 lattice was staggered to place alternate controllers adjacent to control rod banks.

B. Temperature Data

The data which have been reduced for this study consist of temperature maps printed by the Flexowriter temperature recorder at B-pile during two periods of transient operation. One was during the discharge of temporary poison during operation on December 4, 1953, and the other during a scram recovery on July 10, 1954. The incident which most probably could lead to boiling in the active portion of the tubes, aside from reduction of coolant flow, is a power excursion affecting a cell of several tubes. In the simplest case the power generation of the cell rises, with the exit temperatures of the group of tubes rising but retaining essentially the same relative temperature ratios that existed prior to the disturbance. However, operating experience has shown that changes in control rod configurations, such as are required during scram recoveries or discharging of poison columns during operation, can cause distortion of temperature gradients

Figure 2 - Schematic of Controller System

throughout a cell. In this manner, individual tubes may rise in power generation relative to their neighbors beyond that normally expected. It was therefore assumed that the data from these two transient periods would best serve to point out what might be expected of the proposed system of controllers. Those maps chosen for each transient period are one each for the equilibrium periods both prior to and after the disturbance, and two or three during the transient. Also included are equilibrium maps taken prior to and after a shutdown involving a large heavy metal discharge. These data are included to determine whether the hot tubes in a cell surrounding a controller can be predicted following a metal discharge.

C. System Analysis

Assume that it is impractical to move the controllers and that they must always be kept on the same tubes as shown in Figure 3 for the 5x5 cell system and in Figure 4 for the 3x3 cell system. Then from a temperature map obtained at equilibrium, one can determine for each cell

$$\Delta_e^1 = T_{\text{hottest tube in cell}} - T_{\text{controller tube}}$$

where the T's are the indicated outlet tube water temperatures. During transients this Δ will likely change. We would like to know the maximum Δ experienced during the transient. Call this

$$(\Delta_t)_{\text{max}} = (T_{\text{hottest tube in cell}} - T_{\text{controller}})_{\text{maximum during transient}}$$

The major uncertainty in establishing a safe controller trip setting prior to an anticipated transient is then the span (δ) in Δ .

$$\delta = (\Delta_t)_{\text{max}} - \Delta_e^1$$

δ is not completely known as long as we have no continuous tube temperature records during transients. For now, we will have to assume that the maximum δ for any cell is that shown on any one of the spot temperature maps taken during the transient.

If T_{limit} is the normal equilibrium effluent temperature limit for a particular reactor, then optimum protection during a hot startup (or any anticipated transient) will be given by previously setting each controller to trip at:

$$T_{\text{trip}}^1 = T_{\text{limit}} - \Delta_e^1 - \delta$$

For this purpose, that value of δ most easily used for each cell is the maximum expected anywhere in the unit. With more effort, a less conservative (smaller) δ could be determined for each cell on the basis of past experience and knowledge of the current pile loading.

As soon as reasonably stable temperature maps can be obtained and it is quite safe to assume that danger of local transients is passed, new equilibrium deltas (Δ_e^2) may be determined for each cell. Then each controller trip may be adjusted upward to

$$T_{\text{trip}}^2 = T_{\text{limit}} - (\Delta_e^2 + \delta)$$

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Figure 3 - Tentative Controller Distribution for 5x5 Cell System

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Figure 4 - Tentative Controller Distribution for 3x3 Cell System

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Where d is a safety allowance for a possible positive increase in Δ before the next temperature traverse and trip adjustment can be made. It is desirable that d approach zero.

The data existing at this writing concerning the performance of the Panellit system show that the uncertainty of operation of the individual gauges will limit the maximum allowable outlet tube temperatures to about 10°C beneath the actual calculated safe limit. Therefore, the allowable uncertainty in the temperature control system must be less than 10°C in all situations to consider it a reliable performer. This will be measured by the temperature span (δ). δ for a cell should not be more than 10°C during any transient.

D. Hot Start-up - 105-B - July 10, 1954

Five temperature maps were used to analyze this transient. One at equilibrium on July 7, three through the time following the startup on July 10, and one at equilibrium July 16. These show tube temperatures as high as 103° resulting from withdrawing the major part of the control rods to the near side. Heat cycling within cells is evidenced. The most detrimental cycling effect upon the operation of the proposed control system is that caused by removal of a control rod adjacent to the fringe of a control cell.

Figure 5 shows the distribution for the 5x5 cell system of Δ_e^1 from the first equilibrium map and Δ_e^2 from the final map. The distribution in δ is shown and also the change in delta between the first and final maps ($\Delta_e^2 - \Delta_e^1$). Figure 6 gives the same data for a 3x3 cell system. If we assume that these maps include the maximum temperatures of this period, we can conclude for this one hot startup that:

- 1) The average Δ_e is less in the 9 tube cell than in the 25 tube cell but the extreme values are about the same.
- 2) The distribution of δ 's is about the same in each system. All values in both cases are less than 10 degrees.
- 3) Only a very small fraction of the controllers in either system show more than 1° increase in Δ_e between equilibrium conditions on July 7 and July 16. The maximum increase in both cases is 5° .
- 4) Most of the equilibrium Δ 's in excess of 10° arise from controllers located near the pile fringe or a poison column.
- 5) The largest temperature spans (δ 's) are caused by removal of a rod from the fringe of a cell, particularly for near side cells.
- 6) Δ increases are not always caused by an increase of power generation which causes a hot tube temperature to rise faster than that of the control tube. A controller may drop in temperature relative to other tubes in the cell.

Thus, if there had been a 5x5 cell controller system installed it could have been operated as follows. Prior to the hot startup, each controller trip could have been set at

$$T_{\text{trip}}^1 = T_{\text{limit}} - \Delta_e^1 - 10^{\circ}$$

This would insure, with a high degree of confidence, that no tube could exceed T_{limit} at any time during the transient without tripping some controller. The

Figure 5a - Delta distribution of 5x5 cell system from first equilibrium map.

Figure 5b - Delta distribution of 5x5 cell system from second equilibrium map.

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Figure 5c - Distribution of δ ,
for 5x5 cell system where

$$\delta = (\Delta \text{ transient})_{\max} - \Delta_e^1$$

Figure 5d - Distribution of changes
in equilibrium deltas for 5x5 cell
system.

Figure 6a - Delta distribution of 3x3 cell system from first equilibrium map.

Figure 6b - Delta distribution of 3x3 cell system from second equilibrium map.

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Figure 6c - Distribution of δ 's for 3x3 cell system.

Figure 6d - Distribution of changes in equilibrium deltas for 3x3 cell system.

10° uncertainty factor (due to $\delta_{\max}$) would be somewhat equivalent to the present hot startup procedure of reducing the T_{limit} by 10° until a complete temperature traverse is made and the hot tubes located. The controller system, however, is better in that it continuously and automatically monitors the entire pile. In one respect it differs from current procedure. If the Δ of a cell decreases during the transient it would be possible for a controller to be tripped even through no tube in its cell reached the temperature ($T_{\text{limit}} - 10^\circ$). For example, if $T_{\text{limit}} = 105^\circ$, and $\Delta_{\frac{1}{2}} = 10^\circ$, then T_{trip} would be set at 85° . If during the transient Δ reduced to 5° , then the controller would trip when the hottest tube in the cell was only at 90° . However, this would appear to be a large change in Δ and it is believed that the combination of experience and operating procedure will preclude this.

For this particular transient (assuming $T_{\text{limit}} = 105^\circ$ and $\delta_{\max} = 10^\circ$), the three transient temperature maps show 13 control tubes which exceeded the T_{trip} temperature. In all of these cases the temperature of the hottest tube in the cell was between 95° and 105° . For this particular scram recovery no controller would have been tripped by a tube temperature below 95° , the maximum permissible under current procedures for a T_{limit} of 105° .

From a temperature map after the transient, new trip levels could be set at $T_{\text{limit}} - \Delta_{\frac{2}{3}}$. As shown in Figures 5 and 6, there was apparently very little tendency for $\Delta_{\frac{2}{3}}$ to increase more than one or two degrees between successive equilibrium conditions.

It is apparent that operation of the system would be enhanced if those controllers approaching trip settings could be readily determined. This information together with complete temperature traverses by the regular Temperature Monitor and the Flexowriter would permit rapid adjustment of pile operation or controller trip settings. Used in this manner the temperature control system could give protection without restricting maximum safe realizable power generation. In this respect, the 5x5 cell system has an advantage over a 3x3 cell system in that there would be fewer points to observe and readjust.

E. Poison Push During Operation - 100-B

During a startup on December 2, 1953, eight temporary poison columns were discharged during operation. Those discharged were tubes 1376, 3765, 1262, 3787, 1086, 3284, 2070, 0975. Of these eight, only that part of the transient directly attendant to the discharging of tube 3765 was selected for study. This tube was chosen since the combination of its location and the available amount of rod control in the upper bank allowed an increase of power generation in the fringe area of the pile which could be limited at the time only by limiting the level of the pile.

Five temperature maps were used to analyze this transient. These maps sample temperatures from an equilibrium period on November 30, 1953, pile level at 680 mw; during the startup just prior to pushing tube 3765, pile level at 590; after pushing tube 3765; and again at equilibrium on December 8, pile level at 700 mw.

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These maps show that as the general level of the pile is reduced, the near lower corner runs quite cool with hot tubes appearing at the far side of the control rod tips and at the top and near fringe area. Map three shows the effects of discharging tube 3765; heat appears in the top near quadrant and tube temperatures increase generally by about 10° in that vicinity. The heat cycling within cells caused by pushing the poison tube and by inserting control rods near temperature controller tubes is evident. The last map shows the return to general equilibrium conditions.

The data from these maps are summarized as for the hot startup in Figures 7 and 8 for the 5x5 and the 3x3 cell systems respectively. The results are consistent with those obtained from the hot startup data. Again the 3x3 cell system does not appear to have any real advantage over the 5x5 cell system. The δ distributions, which govern the uncertainty in establishing trip settings, are similar for both systems. The largest δ value recorded for the 5x5 system is 6° which is certainly acceptable. The 3x3 cell system, interestingly, shows maximum δ 's of 7° and 8° . This results from several controllers being placed on tubes which show temperatures that stay at about 72° while the temperature of adjacent tubes cycle from a cooler to a warmer level. This behaviour suggests the possibility of a thermocouple lead being shorted so that the reading is proportional to bulk outlet temperature (a crossheader, perhaps) rather than a specific tube temperature.

F. Prediction of Cell Deltas for Cells with Central Tube Controlling

During normal equilibrium pile operation there would be ample opportunity to use complete temperature traverse data to readjust the controller trip settings as required. It is important, however, to be able to successfully estimate the individual cell deltas which will be experienced during operation following an outage during which there was a large metal discharge or change in flattening adjustment. This case was not covered by the two transient studies and has, therefore, been separately considered.

Cell deltas were obtained from an equilibrium temperature map from B pile (May 11, 1954) just prior to a scheduled outage. Considering the metal discharge and flattening adjustments, the individual cell deltas for the post-outage equilibrium condition were estimated. These were then compared with the actual cell deltas as obtained from a temperature map at equilibrium on May 17th. This is actually more restrictive than a real situation since it would have been possible to make trip adjustments prior to May 17th. However, the results are encouraging in that the cell deltas were predicted with reasonable success. Those cases in which the actual values varied from the predicted values by more than two degrees were relatively few. In most cases, these differences are due to a liberal allowance for a cell delta following the discharge of a controller tube.

Assuming normal startup procedures following a routine outage, there should be sufficient opportunity to check the individual controller settings and correct those which are not in agreement with the anticipated values. Under scram recovery conditions following equilibrium conditions, it can be assumed that the above adjustments have been made. Considering only the problem of correctly setting the controllers, the greatest difficulty would be experienced during a startup following a routine outage during which the controller settings were not checked

Figure 7a - Delta distribution of 5x5 cell system from first equilibrium map.

Figure 7b - Delta distribution of 5x5 cell system from second equilibrium map.

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Figure 7c - Distribution of δ 's for 5x5 cell system.

Figure 7d - Distribution of changes in equilibrium deltas for 5x5 cell system.

Figure 8a - Delta distribution of 3x3 cell system from first equilibrium map.

Figure 8b - Delta distribution of 3x3 cell system from second equilibrium map.

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Figure 8c - Distribution of δ 's for 3x3 cell system.

Figure 8d - Distribution of changes in equilibrium deltas for 3x3 cell system.

or adjusted. Even in this case, this study indicates that with experience and reasonable care the cell deltas can be estimated within the range of values shown in the transient data. It also appears that no greater margin of safety from this standpoint is evident in the nine tube cell over the twenty-five tube cell.

G. System with Controller Located on Hottest Tube in Cell

Rather than arbitrarily mounting the controller on the central tube of a cell, it could be placed on the hottest tube in the cell. This would require that some controllers be moved during every outage to the tubes which are predicted to be the hottest for their respective cells during the next operating period. This procedure would be cumbersome and expensive and probably rules out the system as impractical. However, some study has been made of a system which monitors the hottest tube in each cell to assist future planning and evaluate the closeness of temperature control that could be provided. Data from the hot startup and the poison push were analyzed as follows. The first equilibrium map in each case was used to spot the control tubes on the hottest tube in each cell. During the transient, temperature cycling occurred so that a delta (Δ) value appeared in some cells. That is, another tube in the cell became hotter than the control tube. The performance of this system can then be measured by the range of delta values experienced. Ideally they should be zero or negative at all times so that the control tubes are always indicative of the actual maximum temperatures.

For the 3x3 cell system during the hot startup, relatively few cells showed any positive Δ for the entire transient. Most of the Δ 's were three degrees or less with a maximum of four degrees. The large deltas appear from choosing controllers away from control rod positions.

The delta for a particular cell was disregarded if the temperature of its hottest tube was less than the temperature of the control tube in an adjacent cell. Similar results were obtained from an analysis of the poison push transient data. Again most of the deltas were under four degrees. Several exceptions larger than this were found, however, they were traced to faulty thermocouples on the control tubes. In general, control-rod movements and charge-discharge of poison in columns adjacent to controllers result in deltas of about four degrees or less. This system, therefore, gives some reduction in the uncertainty in establishing trip settings from that found with central tubes controlling. There is, however, some uncertainty remaining.

Some consideration was given to the problem of estimating which tubes within the cells would be the hottest following an outage in which there were large metal discharges or changes in flattening pattern. The B pile maps of 5/11 and 5/17 were again used. Predictions were made based on the pre-outage equilibrium map and the charge discharge schedule. The predictions were then compared with the equilibrium map after the outage. Most of the controllers were correctly placed on the hottest tube in their cells. A few cells had deltas of up to three degrees with three cells having a maximum delta of four degrees. In this case, as before, controller trips could be adjusted after startup to take care of any deltas that appeared. In choosing the hot tubes for the period following this particular outage, 42 controllers were moved within their cells. It is estimated that about five hours of rear elevator time would be required to make these changes.

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H. Estimated System Costs

Estimates of the costs of the two systems considered are based upon known costs for the recent replacement of thermocouples in the older piles, and the costs of the monitoring equipment purchased for the K piles. These costs include the purchase price of all components delivered to the plant and the cost of installation and checking the systems. They do not include costs for engineering time or indirect project expenditures. They assume the controllers to be located in the control room or close to it. Ten extra controllers (to be spotted where needed) are included in the figures for both the 3x3 and 5x5 cell systems. The cost estimates are given in Table I.

Table I - Cost Estimate

<u>Item</u>	<u>Cost/Point</u>	<u>3x3 cell - 215 points</u>	<u>5x5 cell - 80 points</u>
Controllers A*	\$ 100.00	\$ 21,500	\$ 8,000
Controllers B* (10 points)	300.00	3,000	3,000
Pigtail Assembly	40.00	8,600	3,200
Resistance Elements	15.00	3,225	1,200
Lead Wires (B,D,DR,F)	7.00	1,505	560
Lead Wires (H, C)	9.35	2,010	750
Install pigtails	6.00	1,290	480
Install control panel	---	900	900
Install Lead Wires (B,D,F)		3,225	1,500
Install Lead Wires (DR)		3,870	1,500
Install Lead Wires (C, H)		4,320	1,700
Equipment to Prepare Thermometer Leads	(Entire project cost for 6 piles - 2,400)	400	400
Measure, Attach Leads	1.20	260	100
Test leads and bulbs before installation	.60	130	50
Install Bulb and Connect Lines	3.60	775	290
Measure Leads and Adjust	3.60	775	290
Test Equipment to Calibrate Controllers	(Entire cost for 6 piles - 600)	100	100
Test and Install Controllers A	1.50	320	120
Test and Install Controllers B	6.00	60	60
Total Cost/Area			
B,D,F		\$ 46,065	\$ 20,250
DR		46,710	20,250
C,H		47,665	20,640
Cost - All Areas		\$ 280,235	\$ 122,270

Estimated Pile Down Time per Area

3x3 cell system - 5 days

5x5 cell system - 3 days

*Controllers A are the permanently located resistance bridge controllers.

Controllers B are the ten servo-type controllers which will operate from the Temperature Monitor thermocouples.

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CONCLUSIONS

This report has attempted to determine, in terms of several particular sets of data, the performance which could be expected from a pile safety system that monitors the exit water temperature of a few selected tubes in the pile rather than every tube.

Study of this problem to date leads the writers to the following conclusions:

- 1) These data demonstrate that a localized temperature controller system can provide adequate trip-before-flow instability protection under most foreseeable conditions. There are possible exceptions; for example, unknowingly charging enriched metal in a regular metal tube.
- 2) The relative low cost and simplicity can probably insure much sooner installation than could be hoped for for an every-tube monitor. Its installation would not necessarily jeopardize later installation of a full-coverage system and would provide a large degree of protection in the interim period.
- 3) The more expensive 3x3 cell system shows little advantage in assured protection over the 5x5 cell system. The 5x5 system offers very real advantages in reduced operating time and costs. No study has been made of more diluted coverage, but the savings in cost would not be in direct proportion to the number of controllers because of certain fixed project charges. It appears that the optimum system might be basically 5x5 cells with additional coverage in the critical region of the rod banks.
- 4) The provision of ten extra controllers which can be plugged into the thermocouple board would provide coverage for known critical tubes.
- 5) It is recognized that the data analyzed for this report came from spot temperature maps and did not necessarily show the maximum temperature changes of the transients. The results are valid, with this understanding; however, it is apparent that more continuous records of tube temperatures during transients will be required to fully specify the operating procedure and limitations of a spot controller system. A development test⁽²⁾ has been initiated for this purpose.
- 6) The span of uncertainty in establishing the proper trip settings could be somewhat reduced by placing the controllers on the hottest tube in the cells rather than the central tubes. However, the need for moving resistance bulbs to appropriate tubes during outages would be costly and time consuming and makes this system impractical.

(2) Paul, R.S. - HW-34367, Development Test No. 105-595-A, "Test of a Cell System Temperature Monitor"

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