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TECHNICAL ACTIVITIES REPORT

HEAT TRANSFER STUDIES

M. W. Carbon
In Charge, Heat Transfer Studies
Pile Technology Unit
Engineering Department

May 1, 1952

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NUCLEONICS DIVISION
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HEAT STUDIES - M. W. Carbon

BOILING CONSIDERATIONS - Tube Temperature Rise Limits - R. G. Vanderwater

Document HW-23284, "Tube Temperature Rise Limits - Boiling Considerations", R. G. Vanderwater, January 24, 1952 has been re-issued as HW-23861, March 26, 1952, to make minor corrections in the Appendix and to provide better graphs. However, the values of the limits as reported in HW-23284 remain unchanged.

BOILING STUDIES - Removal of Downstream Solid Dummies - K. G. Toyoda, R. P. Schmitz,
R. G. Vanderwater

Calculations have been continued to determine the permissible Δt 's for tubes with the downstream, solid-dummy slugs replaced by perforated dummies. The replacement causes the steam-water mixture pressure drop to be decreased and thus permits an increase in the tube boiling limit. The calculations are complicated by the fact that limits for several different conditions must be established. For example, the limits for the B, D, and F Piles will be different from those of the DR and H Piles because the inlet nozzles are different. The limits for tubes with 4" slugs may differ from those for tubes with 8" slugs since the 8" slugs are actually over twice as long as the 4" slugs. Finally, the permissible Δt 's will not increase as much as the permissible power upon replacement of the solids because the flow does not remain constant.

A document giving the new limits will be issued following completion of the calculations.

FLOW RATES - Tubes with Four Perforated Dummies Instead of Solid Dummies - R. P. Schmitz,
R. G. Vanderwater

Experimental pressure drop data was taken last month by R. F. Recht to determine the effect on tube flow rates of replacing the four solid aluminum dummies with perforated dummies. Examination of this data has shown the following increase in flow rates:

ORIFICE SIZE

	<u>0.285</u>	<u>0.240</u>	<u>0.200</u>	<u>0.175</u>	<u>0.140</u>
1. Replacing 4 solid dummy slugs with 4 perforated dummies	3-1/4%	2-1/2%	1-1/2%	1	1/2%
2. Replacing solid dummies and also changing from "4 inch" to "8 inch uranium slugs"	2-1/2%	2	1-1/4	3/4	0.4

The reason for the smaller increases in Case 2 is that the total length of the thirty-two "8 inch" slugs is greater than the length of sixty-four "4-inch" slugs. The greater length of the uranium charge thus counterbalances a portion of the effect of eliminating the solid dummies.

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STATUS REPORT ON RAISING OF BOILING LIMITS - R. G. Vanderwater

A report is being written which will present the status of the work on the various methods by which boiling limits may be raised at the old piles. These methods include the following: (1) raising of header pressure, (2) enlarging the outlet fittings, or (3) relying upon an improved monitoring system. The first two methods do essentially the same thing: They increase the maximum power at which boiling can be suppressed by the header pressure. However, unless the cause of boiling disappears within a few seconds, the monitoring system must be relied upon to detect the condition and to shut down the piles.

To provide more reliable monitoring of tube flow rates, consideration is being given to the installation of a second monitoring system to augment the Panellit system. This has been proposed in "Proposal for the Adoption of a Dual Monitoring System", HW-23845, M. Altman to G. E. McCullough, March 24, 1952. Among the methods being studied for the second system are the following: (1) A mercury jet switch for rapidly scanning the thermocouples which measure the outlet temperature, (2) a second Panellit system based upon the pressure in the rear nozzles, (3) a hot wire device for measuring the outlet temperatures, (4) a hot wire device for measuring the flow, (5) other flow instruments, (6) pop-off valves or rupture discs to provide a means of lowering the flow resistance if boiling should occur.

It would appear that the most desirable monitoring system is one which measures the water temperature since this is a direct indication of whether boiling is occurring or about to occur. Of the temperature devices listed above the mercury switch for scanning the thermocouples appears most favorable at present for the following reasons: (1) development time - seven to nine months, (2) no down time required for installation since thermocouples are already installed, (3) preliminary cost estimate of about \$40,000 to build, test, and to install the rapid thermocouple scanner.

Discussions of a rear nozzle Panellit system and of flow monitoring systems are given elsewhere in this report.

"C" PILE BOILING LIMITS - R. G. Vanderwater

The tube power limits at "C" Pile based on boiling considerations will be considerably higher than those at the other piles because of the larger annulus size and the larger outlet fittings. The limits are given in Figure 1 for the following conditions: (1) a 0.318" orifice, (2) top row tube, (3) 20°C inlet temperature, (4) 11 psi film build-up based on a 20.4 gpm flow rate, (5) tube loading consisting of one 5" and eleven 8" perforated dummy slugs, four 8" solid dummy slugs, and sixty-four 4.35" uranium slugs, and a 23% pile factor to allow for errors in measurements and variations from normal size annulus, fittings, etc.

Because of the larger annulus, the effect of a given amount of film deposited on the slugs or tube will be less than in a tube at one of the old piles. For example, a film of sufficient thickness to cause an 11 psi pressure drop increase in the C annulus would cause a pressure drop increase of about 25 psi in the B, D, F, H, or DR annulus.

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FIGURE 1
REQUIRED HEADER PRESSURES FOR "C" PILE

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BOILING STUDIES CONSIDERATIONS - Secondary Pressure-Monitoring System - K. G. Toyoda

Investigations were continued to determine a means for raising the boiling limits, and hence the tube powers, without increasing the required header pressures or enlarging the outlet fittings. The use of a secondary pressure-monitoring system placed in the rear fittings to detect boiling was considered for supplementing the present Panellit system.

Steam formation in a tube may occur if a sufficient decrease in water flow occurs. The steam formed will increase the pressure in the system as a result of increased specific volume, and therefore, flow resistance.

A logarithmic diagram of the pressure versus the flow rate similar to Figure II below, be drawn for any point such as tube inlet, outlet nozzle, outlet pigtail, or outlet Parker fitting.

The region exemplified by the line AB is the non-boiling region. As an illustration, assume that the pressure-flow relation at the outlet nozzle under normal operation is point X. If the pressure at the nozzle falls below B due to a loss in inlet header pressure, screen plugging, etc., the water flow rate will decrease. Therefore, boiling begins. The flow rate will continue to decrease because of increasing flow resistance by the larger specific volume of the steam formed. The temperatures would increase and damages to the process tubes, the slugs, or the graphite might occur.

Figure 2

If the flow decreases below B and remains so, the time required for the pressure to go from X down to B, and up to some point Z in the boiling region is relatively short. If a secondary pressure-monitoring system is placed in the outlet nozzle such that the lower and the upper trip points are located at some points Y and Z, respectively, the pile can possibly be scrambled before serious process tube, slug, or graphite damages occur.

The maximum pressure fluctuations normally expected in the rear fittings of piles are ± 8.5 psi. In order to place a lower trip, Y, in the rear fittings, a pressure difference greater than 8.5 psi must exist between the normal operating pressure, X, and the lower trip point, Y. From the consideration of the pressure fluctuations, it appears that an installation of any secondary pressure monitoring system in the outlet fittings would be most feasible in the rear nozzle.

Work to determine the feasibility of this secondary pressure monitoring system will continue.

FLOW CHARACTERISTICS OF PILE ORIFICE CONE SCREENS - R. F. Recht.

A test was made in the 100-F flow laboratory to determine the flow characteristics of the cone screen to be used in C Pile. A physical comparison made between this screen and the present screen shows that the base diameter of the "C" cone is smaller and the

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screen has less coarse mesh over its flow area.

Both screens were tested using a 0.285" orifice, standard annulus, and standard loading. After the clean screen data had been taken, the fine mesh in each screen was plugged to an arbitrary but reasonable extent and the test repeated. Due to this type of plugging the flow area presented in the case of the C pile screen was smaller than that of the standard screen. The effect of plugging in regard to the "C" annulus was determined from flow data obtained previously. Results are shown below. A constant header pressure was assumed for presentation of the data.

AP-PSI (Header to Header)		Standard Annulus		"C" Annulus	
		GPM	Percent Decrease in Flow Rate When Plugged	GPM	Percent Decrease in Flow Rate When Plugged
"C" File Screen					
Clean	380	24.6		33.5	
Plugged	380	23.0	6.5 %	30.0	10.5 %
Standard Screen					
Clean	380	24.8		33.9	
Plugged	380	24.2	2.4 %	32.5	4.1 %

Originally, the screens were plugged in order to determine the relative effect of plugging in each screen. This is shown by comparing the percent of decrease in flow rate for each screen when plugged. It should be pointed out that plugging becomes more serious as the tube annulus size is increased. This is true because the pressure drop through the orifice and screen is a larger proportional part of the total pressure drop, header to header. Therefore, even if the present type screen were used in C Pile, plugging would become a more serious problem than it is at present.

As indicated in the data, a decrease in flow rate of about ten percent might result from a plugged C Pile screen used in C Pile compared to a 2½ percent decrease from a plugged standard screen used in the present piles. Installation of the C Pile screens might well lead to operational difficulty if clogging did occur in the above manner.

TESTING OF TIME DELAY RELAY - Production Test 105-502-E - W. D. Gilbert

Additional operating data were obtained from the time delay relays installed in 100-B Pile. For a period of 31 days, no Panellit alarms were observed, and no operational difficulties resulted from the use of the relays. Thus at 100-B Pile, no shutdowns have resulted if the Panellit alarm system had been on an instantaneous scram basis.

No operational difficulties were encountered at 100-D and 100-DR Piles with the time delay relays. However, a shutdown resulted at both 100-F and 100-H Piles. At F Pile

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on April 19, 1952, a shutdown resulted from a continuous high pressure in tube 0378 in the 0.175" orifice zone. The upper trip point for the Panellit gage was 18⁴ psi, and the time delay period was three seconds. Data were not obtained for the tube outlet water temperature before the pile scrambled. After the pile was scrambled, the tube inlet pressure was found to be 195 psi as measured on the Heise gage. Normal tube inlet pressure for the tube is 115 psi. The high pressure resulted from plugging in a downstream section of the tube. It was believed that a rubber gasket had been left in the rear of the process tube when the tube was being checked for water leaks. The gasket evidently worked into a position where it could partially block the water flow, causing the increased tube inlet pressure and the resulting scram. It should be noted that the time delay relay functioned effectively to scram the pile before damage could occur within the process tube.

The 16-minute shutdown at 100-H Pile on April 17, 1952, resulted when the Panellit circuit was inadvertently opened as the Instrument mechanics were testing and working on a Panellit gage. The shutdown was not occasioned by a malfunction of the time delay relay or of the Panellit system.

The delivery date of the flux decay relay has been set back for about six months due to unavailability of parts. It is anticipated that the flux decay relays will replace the mechanical Microflex relays which are now in use. In the meantime, a final report will be written on this Production Test. However, the taking of Panellit trip data will be continued in order to determine the feasibility of placing the Panellit System on an instantaneous, automatic scram basis.

COOLING WATER FAILURE IN HANFORD TYPE REACTORS - M. Altman

The preliminary phase of this investigation has been completed.

There are, in general, three ways in which a reactor catastrophe can be brought about.

1. Mechanical Disruption
2. Reactor Runaway
3. Cooling Failure

Mechanical disruption could be the consequence of an earthquake, bombing, or sabotage.

Reactor runaway could be produced by the release of excess reactivity in the piles. The removal of control rods, or the sudden loss of a poison (cooling water, for instance) would make a reactor supercritical.

The permanent loss of the reactor cooling water, in the absence of excess reactivity, might lead to the destruction of the piles by melting of the reactor constituents. This study is being restricted to the consequences of a cooling water loss. Such a loss is of a less serious nature than the other possible situations. The longer a pile has been shut down before a cooling failure occurs, the more time will be available before temperatures high enough to cause melting of pile components would be reached.

As a first step, in this investigation, it was decided to prepare a set of curves which would present the calculated temperatures of the various pile components as functions of time under a variety of conditions.

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Figure 3 is a sample of the type of curves being calculated.

It is planned to calculate such curves for a variety of values of time after shutdown before cooling loss occurs.

An attempt will also be made to analyze and predict the consequences of cooling loss on the pile buildings and surrounding areas.

The calculations are involved, and are complicated by the fact that almost all variables are functions of temperature, and, therefore, indirectly of time.

Analytic solutions were obtained, but were so cumbersome that the aid of the Computing Section has been enlisted. The programming of the IBM machines has been completed, and results will be published periodically as they become available.

MEASUREMENTS OF SLUG BOND COEFFICIENTS - D. E. Amos

The blueprints for the construction of the conductivity apparatus have been checked, and a few minor changes made. The resulting corrections in drafting are expected to take a few days. Upon completion, the machine work and construction will start.

THERMOCOUPLE SLUG - W. D. Gilbert

Installation of a thermocouple slug in one of the piles has not yet been completed. Difficulty has been encountered in drilling the small 0.076 inch diameter thermocouple well in the center of the uranium slug. The thermocouple well will be redesigned, using a larger hole. This may permit easier drilling of the hole and more rapid completion of a thermocouple slug.

Development work has continued on a thermocouple slug containing an axial and a surface thermocouple. For the surface thermocouple, a small groove will be machined on the surface of the uranium metal, then a butt-welded thermocouple will be cemented into the groove. Finally a thin layer of metal will be electroplated over the groove, the thermocouple, and the surrounding area. This latter will be necessary in order to obtain a satisfactory bond between the slug and the aluminum can.

With the slug containing two thermocouples, it is anticipated that the thermal conductivity of the uranium may be obtained under conditions of irradiation. Also more accurate data may be obtained on the effect of film on the surface temperature of the aluminum can.

FILM FORMATION STUDIES EXPERIMENT - 105-Flow Laboratory - K. G. Toyoda, H. H. Greenfield

A test on the equipment for fundamental film studies was completed during the month. The test was designed to obtain scale heat transfer data to supplement the results of the Pressure Drop Film Studies.

Water was passed through an 1/8 inch wide channel formed by 2-S and 72-S aluminum plates at a flow rate of approximately 4.6 gpm. The height of the channel was one-inch. The

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NOTE: T IS THE TIME BETWEEN SHUT DOWN OF REACTOR
AND OCCURANCE OF COOLING FAILURE — HOURS

FIGURE 3. ESTIMATED SLUG TEMPERATURES AFTER COOLING FAILURE
(ORIGINAL POWER LEVEL — 800 MW)

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fluid pressure drop from the inlet to the outlet of the equipment was maintained at 30 psi throughout the test. The total operating time was approximately 11 days. The water entered the equipment at about 10°C and was discharged at about 80°C.

Local water temperatures, aluminum plate temperatures, steam side plate surface temperatures, pressures, and water flow rates were obtained periodically. The local water temperatures were measured by means of a "sliding" thermocouple. The thermocouple was placed inside of a 1/16" O.D. stainless steel tube fixed in the water channel. The thermocouple was moved to any desired point along the plate length, and local water temperatures were measured. The aluminum plate temperatures were obtained by a series of permanently fixed thermocouples. Thickness of the scale formed along the plates were measured upon completion of the tests.

From the above data, it should be possible to determine the heat transfer characteristics of the scale. The data have not been analyzed as yet.

RESISTANCE HEATING OF SLUGS - R. Neidner

Assembly of the Resistance Heating Equipment (RHE) to be used for the experimental study of slug stresses has been almost completed. A schematic sketch is included, Figure 4, to show the general layout of the equipment. Also included below is a tentative list of initial equipment tests and the initial slug stress tests. This tentative list should cover the time from the end of April to the end of July. This estimate is based mainly on having the availability of the current generator set at the 189-D building split equally between the Tube Mock-Up and the RHE.

Initial equipment tests to be run after completion of all components of the RHE will be as follows:

1. Low power tests without flow of cooling water, for determining electrical resistivities of bonds and threaded couplings of the specimen with zero end pressure; also, to check efficiencies of electrical bus work and heater heads.
2. Low power tests with cooling water flow, to determine the relation of bond electrical resistance to specimen end pressure.
3. Instrumentation checks pertaining to temperature recordings, pressure readings, and cooling water flow control.
4. High power tests to determine axial temperature build-up, and the relation of this temperature build-up to total current flow and generator power output.

The first slug stress tests to be run with the new RHE are proposed to be two-fold. First, the tests will be run at thermal conditions that shall closely simulate the actual in-pile slug conditions. This will be done in an attempt to cause a condition of distortion, or rupture, similar to the distortion that has occurred in certain pile-heated slugs. Second, to correlate these "new" data to data that have already been taken in similar tests at Oak Ridge.

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FIGURE 4
RESISTANCE HEATING EQUIPMENT

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The slug stress tests will be run using the standard alpha rolled, triple-dipped, four inch slugs. The equipment can handle from one to three slugs at a time. In case of a specimen containing two or three slugs, the slugs will have to be brazed together. This brazing procedure has apparently never been done at Hanford and techniques are being worked out. Possibly, help to this brazing problem could be obtained from Oak Ridge. Until the multi-slug specimen are made up, the tests will be run with single slugs.

Tentatively, the first slug test following the preliminary equipment tests will run on the following cycling schedule: 20 minutes to go up to an axial temperature of 300°C, five minutes at a constant 300°C, 20 seconds for reduction of heating current to zero. This cycle will be repeated as long as the specimen permits, or, to a point of 75 cycles. The 75 cycle limit is approximately three times the average number of cycles that each of the pile's first 67 ruptured slugs were subjected to. It would not seem justified to continue beyond this point.

Following the tests with the Al-Si bonded slugs, tests will be made on specimens that have been canned by the method of high heat and pressure (no Al-Si bonding, purely Al-U fusion). It is hoped that the anticipated difficulty of bond failure at high heat generating currents can be over-come by this canning method. The tests on the fusion bonded specimen will have the same schedule as the Al-Si bonded slug so that an order may be placed for the fabrication of specimens with the best characteristics for resistance heating.

Schedules for further tests having new cycling time tables and for going to higher, or lower axial temperatures will be made. These schedules will be dependent on an analysis of the equipment operating qualities and the thermal and the mechanical conditions necessary for simulating a specific slug condition.

CORRECTION OF TEMPERATURE READINGS FROM G-THERMOCOUPLES AT B, D, AND F PILES -

H. H. Greenfield

In order to help maintain the pile power at the maximum production level from a graphite burnout temperature limit, corrections of the temperature readings from the G-thermocouples for the B, D, and F piles were made. These corrections are based on conservative estimates of the errors in the readings from the G-thermocouples. The errors were determined from comparisons of graphite temperatures measured by G-thermocouples, C-Test Hole thermocouples, and vertical safety rod thimble thermocouples. At the present operating levels and graphite temperatures at F Pile, it was found that G-14 apparently reads about 10°C high and G-13 reads about 30°C high. At D Pile, G-14 indicates about 10°C high and G-13 reads about 20°C high. Comparisons of G-13 thermocouple temperature data with C-Test Hole thermocouples at B pile indicate that G-13 reads about 10°C high.

The temperature corrections that are being applied to each G-thermocouple reading at each pile are given below:

<u>Pile</u>	<u>G-Thermocouple</u>	<u>Temperature Correction (subtracted from G-thermo- couple reading) °C</u>
B	13	10
	13	10
	14	5
F	13	15
	14	5

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SHIELD TEMPERATURES WITH NO WATER FLOW IN THERMAL SHIELD COOLING PIPES - PT-105-515-A -
W. D. Gilbert

An in-pile test will be conducted to determine the temperatures which result in the shield components when water is shut off from thermal shield cooling pipes during pile operation. Thermocouples will be installed in the thermal shield cooling pipes adjacent to thermocouples located in the biological shield. Water will then be turned off from selected thermal shield cooling pipes, and equilibrium temperatures of the shield components will be monitored. Water flow and temperature rise data of the cooling water will be obtained in order to estimate the heat generation rate in the thermal shield. These data should provide sufficient information to establish a more accurate basis for the Process Specifications, and to provide useful design information. A production test is being circulated for approval.

THERMAL EXPANSION OF THE SIDE THERMAL SHIELDS OF C PILE - C. Warren

A brief study was conducted to investigate some performance characteristics of the side thermal shields of C-Pile. It was feared that, due to changes in the construction procedure, operating performance might be impaired. Calculations were made to determine the magnitude of thermal expansion and its effects. The conclusion was that the most serious effect of thermal expansion will be a distortion of the thermal shield cooling pipes. However, it was further concluded that the situation was not serious enough to warrant a change in the side thermal shields from the way they have been constructed.

A brief discussion of the factors considered in the study is contained in a letter to W. R. Lewis from C. Warren, "Side Thermal Shields of C Pile", April 8, 1952.

DISTORTION AND STRESS IN THE BIOLOGICAL AND THERMAL SHIELDS OF B, D, AND F PILES -
C. Warren

Work is being continued on a report which will provide a discussion of the stress conditions in the biological and thermal shields of B, D, and F piles. The objective of the report will not be to present a compendium of data on shield motions but rather to provide a summary of work which has been done in an attempt to predict possible shield conditions that may arise in future operation.

STUDIES OF HIGH DENSITY CONCRETE FOR BIOLOGICAL SHIELDS - C. Warren

A program is being formulated to study and develop high density concretes for shielding purposes. At the present time an outline is being prepared which will (1) define the objectives of the work which will be performed, (2) state the general policy which will be followed in investigating new concrete materials, and (3) list in detail the equipment and tests necessary to design and evaluate the engineering properties of new shielding concretes.

Tests are presently being conducted to determine the water retention qualities of some Portland cement-limonite grouts. It is believed that the tests will aid in predicting the amount of water that will be retained in an iron-limonite concrete shield placed by the intrusion grouting method.

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TEMPERATURES WHICH MAY OCCUR IN C-PILE HORIZONTAL RODS - W. D. Gilbert

An investigation was made of the temperatures which may be encountered in the components of the Horizontal Control Rods at C-Pile. It was found that near the exit end of the rod, the surface temperatures of the aluminum cans containing the boron may approach 65°C , and the boron temperature may exceed 85°C . Because the can wall is to be only 0.040 inch thick, the useful life of the rods may be limited to five to seven years due to corrosion of the aluminum cans. Local pitting corrosion and film build-up on the outer can wall may decrease the rod life still further.

If the small 0.040 inch outer annulus becomes plugged, the outer can-wall temperatures may reach approximately 250°C ; and the inner can wall, approximately 95°C . These temperatures would probably cause considerable corrosion damage to the cans containing the boron.

To prevent possible plugging of the small outer annulus in the rod, it is recommended that a 30 mesh screen be provided at the inlet rod water source. Also, means should be provided for removing the film which may build up in the rods.

INX FACILITY TEMPERATURES - D. R. Amos

The proposed pile control mechanism using a ten percent boron solution is being analyzed for maximum temperatures to determine the probable corrosion rate and life of the apparatus. This apparatus, through which is circulated the boron solution, is to be inserted in a process tube for additional pile control. It acts as a multiple pass heat exchanger since the boron solution enters and leaves on the rear face. Essentially all of the cooling of the boron solution is done by the process water since the external circuit depends upon natural convection for cooling.

The formulae for the temperatures along the tube are being developed.

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