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TUBE POWER LIMITS - PAST, PRESENT
AND FUTURE

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TUBE POWER LIMITS - PAST, PRESENT AND FUTURE

INTRODUCTION

During the history of operation of the Hanford reactors, several methods have been utilized to establish an outlet water temperature or "Panellit" limit based on the stability of water flowing through the process tubes. These methods have been known as "Excess Header Pressure Limits", "Trip Before Boiling Limits", and the most recent, "Trip Before Instability Limits". Each new concept was accepted only after considerable experimental data had proved the new method to be safe and operationally feasible. It is anticipated that in the future other tube outlet water temperature limits will be developed based on new technology. The purpose of this document is to present, in simple terms, an understandable explanation of previous operating limits, to discuss the status of the present Instability Limits, and to outline the direction of future work in raising the outlet water temperature limits.

SUMMARY

Tube power limitations at the Hanford reactors have been based on two different basic concepts. Until quite recently the reactors were operated on the "Excess Header Pressure Limit". Under that method, the tube powers were maintained sufficiently low such that if the water flow rate were reduced or momentarily stopped, the high available process water pressure would sweep the steam from the tube. This method was inefficient and did not provide adequate protection against slug melting if a continuing water flow stoppage occurred within a process tube.

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As a result, a new method was adopted which relied upon instrumentation of individual tubes to maintain safe operation. This method was termed "Trip-before-boiling". Later the concept and limits were modified and termed "Trip-before-instability". Basically, this method requires that the water flow rate of each process tube be monitored continuously with a Panellit gage and that the pile be scrambled immediately in case of abnormal flow. Because the Panellit gage monitors pressures only, the system is subjected to certain limitations. However, even with these limitations, it is possible to allow tube outlet temperatures in the order of 120 C.

By making certain modifications to the piles, (these modifications may prove to be quite extensive in practice) and by making provisions for removing the steam which will be generated, it should be possible to permit outlet temperatures in the order of 160 C. These limits are based upon stability of flow through the process tube. Other factors, such as tube power surges, steam pump failure, or strength of rear piping components, may place temporary limitations on the permissible tube powers. Additional instrumentation, such as thermocouples or flow meters may be required to alleviate the limitations.

The bulk of this document is a discussion of the methods by which the Panellit gages are utilized in establishing the operating limits. This discussion is not detailed, it presents concepts rather than actual number.

DISCUSSION

A. Basic Technical Criteria

In order to understand the discussions which will follow, the basic technical points necessary for an understanding of the problems will be considered first.

The pressure required to maintain water flow through a process tube is a function mainly of the tube and slug geometry, the associated tube fittings, the outlet water temperature or tube power, and the rear header pressure. This pressure required can be specified as a header pressure, an orifice pressure, a tube inlet pressure, or a pressure drop across the tube and rear fittings. For convenience in this preliminary discussion, the tube inlet pressure will be considered. The pressure-flow diagrams will be shown as logarithm pressure vs logarithm flow.

It has been found both experimentally and theoretically that the tube inlet pressure, P_t , and flow rate, W , can be correlated as a straight line on a log-log plot. Thus, if hot or cold water is flowing through the process tube, and the tube is generating no heat, the curves are as follows:

FIGURE 1 - PRESSURE-FLOW, NO HEAT REMOVAL

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Curve "a" is for cold water, and curve "b" for hot water. Lower pressure is required for the hot water at a given flow rate because of the lower viscosity and thus lower resistance to flow. If heat is removed as the water passes through the tube and no boiling occurs, the exit water temperature is higher than the inlet, and the pressure required lies some place between curves "a" and "b". If the water flow rate is decreased sufficiently so that boiling occurs in the rear fittings or in the tube, the straight line correlation no longer holds, and the pressure-flow relationship is about as follows:

FIGURE 2 - PRESSURE-FLOW, HEAT BEING REMOVED

The upward swing of the curve in the "Boiling Region" is caused by the increased pressure drop of the steam-water mixture across the rear fittings. It is important to note that the curve of Figure 2 is characteristic for a given tube and fitting geometry. For example, the flow annulus and the rear fittings are smaller at the B, D, F Piles than at the C and K Piles, so that different curves are obtained for the same tube power, as in Figure 3.

FIGURE 3 - EFFECT OF TUBE RESISTANCE

Of great significance is the effect of power increase on the required pressure. For a given flow rate, as the tube power is increased, the required tube inlet pressure increases, resulting in a family of curves as follows:

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FIGURE 4 - EFFECT OF TUBE POWER

It has been found that the shape as well as the relative position of these curves changes as the tube power is increased.

It should be noted here again that all of the above curves show the tube inlet pressure required or necessary to maintain the given flow rates. That is, the shape of these curves depends upon the conditions of the tube, the tube fittings, and the water temperature downstream from the tube inlet.

Sufficient pressure must be available upstream from the tube inlet to provide the required flow for a given operating condition. This can be plotted as tube inlet pressure vs flow considering only the (a) front crossheader pressure, and (b) the pressure drop across the orifices or venturis. These curves are as follows:

FIGURE 5 - AVAILABLE PRESSURE WITH AN ORIFICE

FIGURE 6 - AVAILABLE PRESSURE WITH A VENTURI

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Because the venturi is a more efficient flow monitoring device, it provides higher tube inlet pressures and flow rates with the same front crossheader pressure than an orifice. If there were no pressure drop across the inlet fittings and venturi, the tube inlet pressure would be the same as the front crossheader pressure. Thus, the front header pressure is the limit of the pressure available at the tube inlet if a large restriction occurs within the tube.

If Figures 2 and 6 are combined, it is possible to predict the tube flow rates under a variety of conditions. Any of the following may result:

FIGURE 7

FIGURE 8

FIGURE 9

Several important facts are seen from these curves. First, flow through the tube can be established only where the available pressure equals the required pressure, that is, where the two curves cross. Thus, a flow can actually exist at all of the Points "a", "b" and "c" in the above Figures.

A second important consideration is the condition of the water at the rear crossheader. If the flow rate is greater than X , such as indicated by the intersection at "a" in Figure 7, then hot liquid water is flowing into the rear header. If the flow rate is less than X , as at "b" or "c" in Figure 8, then steam or a mixture of steam and water is flowing into the rear header. It has been found experimentally that when the flow rate is at or below Y , the slugs are blanketed by steam, and if the tube power is high enough, burnout occurs (jackets, tube and slugs melt). Thus in Figures 7 and 8, points "a" represent normal flow with adequate cooling, and point "c" represents flow rates at which burnout might occur.

A third important factor concerns stable flow vs unstable flow. Points "a" and "c" of Figures 7, 8 and 9 are stable flow points. This is so because if the flow fluctuates in the positive direction, the available pressure is less than the required and the flow rate will decrease to the original value. By similar reasoning, stable flow cannot exist at point "b" in Figure 8, and the flow will progress to either "a" or "c". This progression will occur in a matter of seconds, but the actual rate will depend upon the tube power and the available pressure.

Enough basic information has been presented so that we can now discuss these curves in terms of pile operating limits.

B. Excess Header Pressure Limit

Originally the old piles were operated on the basis of an "excess header pressure" or "boiling disease" limit. This limit was a tube power limit rather than a Δt or out-

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let temperature limit. Basically the concept was that the available pressure had to be greater than the required pressure as shown in Figure 10, and could not be as shown in Figure 11. At the time these limits were in effect, orifices were used on the inlet fittings to conserve water, so the curves were usually drawn as follows:

FIGURE 10

FIGURE 11

The important concepts of this boiling disease limit were as follows: (1) if the flow decreased temporarily for some reason, such as temporary cone screen plugging in Figure 10, steam would be formed, but the excess header pressure would sweep the steam from the tube and return the flow to normal when the restriction was removed, and (2) if the restriction were not removed and normal flow were not returned, burnout or slug melting could occur.

The fallacy of this concept was the assumption that the abnormal flow rate would occur only momentarily, and that normal conditions could be resumed quickly. In practice, rectification of the abnormal condition could seldom occur in time to prevent slug melting. The trip settings of the Panellit gages were inadequate to scram the pile automatically in sufficient time to prevent slug damage.

From the above considerations, it can be seen that a point would be reached (about 450 kw/tube at the B, D, F Piles in practice) where the tube power could be raised only by increasing header pressure or decreasing the tube resistance. Therefore, as a result of considerable experimental studies, a new concept was evolved which depended upon tube instrumentation for adequate protection.

C. Trip Before Boiling Limits

As discussed above, the excess header pressure limits did not actually provide protection against slug melting if abnormal flow conditions occurred and persisted. By making simple changes in the Panellit settings, however, it was found that the tube power could be increased under the trip before boiling concept and still be safer than at low powers with the excess header pressure "protection".

The basic criteria for this concept was to set each Panellit such that, if the flow rate in the tube decreased, the Panellit gage would scram the pile before boiling developed in the rear fittings. It was found that for most cases of abnormal flow, the pile would be scrambled in time to prevent tube boiling and thus prevent jacket, slug and tube melting. Thus, the whole concept could have been termed "Trip in time to prevent melting".

The technical and operational basis for this concept was that any type of flow reduction could be detected using the Panellit gage. In general there are three causes for a flow reduction: (a) rupture of inlet tube fittings, (b) cone screen plugging and (c) down-

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stream restriction such as tube plugging, plugging of outlet fittings, or increase of rear header pressure. Using a venturi, the tube inlet pressure-flow diagrams for these various cases are as follows:

FIGURE 13 - RUPTURED INLET FITTINGS OR REDUCED FRONT HEADER PRESSURE

FIGURE 14 - CONE SCREEN PLUGGING

FIGURE 15 - TUBE PLUGGING

Considering Figure 12, it can be seen that normally the operating flow is at point "a" in the all liquid region. Fundamentally, the flow can decrease only by progressing along the intersection of the curves representing pressure available and pressure required. Thus, in Figure 12, the flow and pressure can decrease or increase along curves "aboc".

It can be seen from Figures 13 and 14 that the ruptured inlet fittings or plugged cone screen have the effect of reducing the available tube inlet pressure, so that the flow and pressure decreases from "a" toward "b". When the condition gets worse than indicated by curve (3) the flow rate will decrease rapidly from "b" toward "c", and burnout will occur unless the tube power is reduced. Likewise, from Figure 15, it can be seen that as the plugging progresses, the flow rate will decrease and the pressure will increase along the curve "aoc". Again, when the plugging gets worse than (3), the flow rate will rapidly decrease toward "c". Thus, in all cases, the flow reduction from point "a" to "b" results from the plugging or fittings rupture, but when the pressure required curve and the pressure available curve can no longer intersect, the flow decreases at an accelerated rate along the pressure available curve to point "c". When the pressure and flow reaches the values indicated by point "c", stable flow will again be established. However, the slugs will be inadequately cooled at point "c", and burnout will occur.

It can be concluded from Figures 13, 14 and 15, that if we can scram the pile at or slightly above flow rate "b", then we can rapidly reduce the tube heat generation rate and either prevent tube boiling or provide adequate cooling before melting occurs if boiling does occur. Thus, the basis for "trip-before-boiling" is to scram the pile before the flow rate has decreased to the value indicated by point "b" on Figures 13, 14 and 15. In utilizing this concept, the problem is to devise suitable methods of scrambling the pile at the proper tube flow rate.

The pile could easily be scrambled at flow rate "b" if a true flow meter were used. The pile can also be scrambled by using an orifice or venturi and monitoring pressures with a Panellit gage. As discussed previously orifices are used mainly to conserve water. However, in the central zone tubes of the pile, it is now desirable to maintain the highest flow rates possible. When the orifice size was increased, the sensitivity of the Panellit gage to the upper trip was decreased. This necessitated the use of venturis, which provided an adequate pressure drop to be monitored, but at the same time recovered most of this pressure drop so that an increase in flow resulted. A comparison of tube inlet pressure and venturi throat pressure for a boiling curve looks as follows:

DECLASSIFIED

- 9 -

FIGURE 16 - COMPARISON OF TUBE INLET AND PANELLIT PRESSURES

Pressures "a" and "b" are corresponding Panellit and tube inlet pressures at the same flow rate. The minimum or instability pressure is at about the same flow rate for both the tube inlet pressure and the Panellit gage. The Panellit gage can thus be used to set the trip limits which were calculated from the experimental tube inlet pressures.

Let us now consider the high and low trips and how they are set on the Panellit gages. Consider the following curves based on Panellit pressures and representing cone screen plugging for the low trip:

FIGURE 17 - CONE SCREEN PLUGGING AND LOW TRIP

From the boiling curve, "abc", it was assumed that boiling occurred in the rear cross-header when the tube flow rate corresponded to W_b . It was also assumed that the curve had a sharp break at flow W_b . The low trip is set at least 10 psi above the pressure which exists at "b". This 10 psi is a safety factor to allow for errors in Panellit calibration and for errors in determining the shape of the required pressure curve. It should be noted that if the low trip were set 15 psi lower, it is probable that the low trip would never be activated in the case of slow cone screen plugging, and burnout would tend to occur. In this case, the pressure would increase and the flow would decrease along curve (3), and the high trip would be activated only after the flow had decreased well into the boiling region. At present, enough experimental data are not available to determine if burnout would occur under these conditions before the pile could be shut down, but there is a chance that this would be the case. Therefore, it is desirable to take every precaution to prevent cone screen plugging.

For the case of the high trip, caused by tube plugging, the venturi characteristics curve remains constant, but the position of the boiling curve changes.

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FIGURE 18 - TUBE PLUGGING AND HIGH TRIP

For this case the high trip is set at 5 psi below the pressure which exists at point O. This 5 psi is a safety factor to allow for errors in the Panellit gages. In this case an error in the Panellit setting is not too critical because as the downstream plugging increases, the Panellit pressure continues to rise with decreased flow rate, along line "aoc", and the Panellit is sure to trip within a few points of the trip point. Thus, the Panellit gage is set to scram the pile at a flow rate slightly above that rate at which the flow would rapidly drop from "o" to "d", where burnout might occur.

It can be seen from the foregoing discussions that with a very narrow spread between the upper and lower trip points of the Panellit gage (say 10 psi), it would be possible to scram the pile with correspondingly small changes in tube or cone screen plugging. Consequently, in theory, it would be safe to operate with a tube outlet temperature close to the boiling point or the minimum of the boiling curve. However, in actual practice, because of differences in sizes of slugs, fittings, and tube, and because of film build-up within the tube, it is practical to operate with a wider trip range. However, this means that the sensitivity of the Panellits to detect cone screen or tube plugging is decreased. Consequently, for the same degree of operating safety, it is necessary to restrict the tube outlet temperatures to values considerably less than the boiling temperature.

Another factor also affects the Panellit gage sensitivity, i.e., the proximity of the operating pressure to the trip point. If the operating pressure lies midway between the upper and lower trips, then the sensitivity to both cone screen and tube plugging is about equal. If the operating pressure is within a few pounds of the upper trip, then the sensitivity to tube plugging is high, but the sensitivity to cone screen plugging is low. A corresponding condition exists for operation within a few pounds of the low trip.

This Panellit sensitivity has been taken into account in establishing the trip limits. In the Process Specifications and other documents, frequent use has been made of the "G" factors. These "G" factors are merely an expression of the Panellit gage sensitivity or efficiency in detecting a decrease in tube flow rate as a result of cone screen or tube plugging. If the "G" factor is high, then the sensitivity is high, and a high outlet temperature is allowable. For each Panellit gage there are two "G" factors, one for high trip and one for low trip sensitivity. In actual practice, the lower value of the two is used to determine the operating limit.

The following curves will illustrate the meaning and use of "G" factors:

DECLASSIFIED

- 11 -

FIGURE 19 - SMALL TRIP RANGE - HIGH "G" FACTOR

In Figure 19, only a small change in flow is required to cause the Panellit gage to scram the pile.

FIGURE 20 - LARGE TRIP RANGE - LOW "G" FACTOR

In this case, a large change in flow is required to scram the pile. The flow and pressure changes from "a" to "b" at high trip, and from "a" to "c" at low trip.

FIGURE 21 - HIGH OPERATING PRESSURE - LOW OPERATING "G" FACTOR

Figure 21 represents a combination of high and low "G" factors. Because the operating pressure is close to the upper trip point, the flow will decrease only from "a" to "b" before scrambling, so that the "G" upper is high. On the other hand, if cone screen plugging occurs, the flow will decrease from "a" to the trip point at "c", so that the "G" lower is low. In calculating the allowable outlet water temperature limit, the value of "G" lower would be used.

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D. Trip Before Instability Limits

Trip-before-boiling was defined above as tripping at a flow rate slightly above that at which the flow becomes unstable and rapidly decreases to the burnout region. In addition, the instability flow rate was thought to be the same as the rate at which boiling would occur in the rear crossheader. Subsequent study led to the knowledge that the boiling flow rate and instability flow rate are not necessarily the same.

Basically, there is no difference between Trip-Before-Boiling and Trip-Before-Instability. At low tube powers, of about 500 kw, the boiling flow rates and instability flow rates were found to be about the same. However, at higher tube powers and higher flow rates, it was found that the instability flow rate was less than the boiling flow rate. Because instability is the important concept, the trip before boiling terminology was dropped, and the trip-before-instability was adopted.

The above can be explained as follows:

FIGURE 22

FIGURE 23

Figure 22 represents what was thought to be the case for the trip-before-boiling. That is, the boiling flow rate and instability flow rate were the same. Figure 23 represents the actual, typical case, and shows that the boiling flow rate, W_b , is not the same as the instability rate, W_i . The relationship between the boiling and the instability flow rates varies with the flow rate and tube power. This was not recognized at first because most of the piles were operating at tube powers in the order of 400 - 500 kw, where the two rates are the same. The variation in the two rates is due in part to boiling in the outlet Parker fitting. The conditions at the various tube powers are shown in the following curves:

FIGURE 24 - 200 kw

FIGURE 25 - 400 kw

FIGURE 26 - 800 kw

VARIATION IN SHAPE OF INSTABILITY CURVES

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It can be seen from Figures 24 - 26, that as the flow and tube power increase, the instability flow decreases with respect to the boiling flow. At low tube powers, i.e., 200 - 300 kw, the instability flow rate is higher than the boiling rate. However, it was found that it was not unsafe to use the boiling flow rates in establishing the operating limits, since about 5 psi safety factor still remained for the low trip.

It has been assumed in all of the above discussion that flow instability occurs in a tube when the pressure decreases to the minimum of the boiling curve, as point "i" in Figures 24 - 26. However, this is not the case. Actually stable flow exists wherever the pressure available curve intersects the pressure required curve. Thus, the following cases represent stable flow at point "a" even though the flow rate is less than that as represented by W_1 :

FIGURE 27 - STABLE FLOW
LOW TUBE POWER - SMALL ORIFICE

FIGURE 28 - STABLE FLOW
HIGH TUBE POWER - VENTURI

This fact is particularly important for establishing the limits of low powers tubes. With cone screen plugging, it is probable that flow instability would not occur because of the available excess header pressure. For downstream plugging, instability conditions can exist, but the high trip of the Panellit gage can be set to scram the pile before instability does occur.

At the higher tube powers and flow rates, the instability flow rate is less than the boiling flow rate. That is, stable pressure and flow conditions do exist in the tube at the flow rate where the water entering the rear crossheader is just boiling. Thus, higher outlet water temperatures, and tube power increases, were permissible under the "trip-before-instability" concept.

In establishing the actual operating limits, a relatively large amount of conservatism was added to the experimental data. This was done as shown in Figure 29.

FIGURE 29 - CONSERVATISM IN THE INSTABILITY LIMIT

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Only for the high trip

Referring to Figure 29, the minimum point of the curve "i" is commonly identified as the point of instability flow and pressure. For a given tube power this corresponds to a unique instability flow and temperature. However, it is not easy to express this flow rate in terms of changes in the Panellit gage. For this reason, the straight line portion of the boiling curve was extended, and the flow rate as shown by "L" was used to calculate the operating instability limits. For a tube power of 900 kw, the difference in temperature between these two points is in the order of 20 C. Thus, an additional safety factor of about 10 - 15% is inherent in the present concepts.

The instability limits are not the same at all of the piles. The larger annuli and larger outlet fittings at the C and K Piles cause different pressure drop characteristics, so that the boiling flow rate and instability flow rate are about the same. Thus, the instability temperatures at C and K Piles are lower than those at B, D, F, DR and H Piles. The instability temperatures for C and K Piles are about equal.

As a final consideration, it has been found that the instability flow rate is also affected by changes in the rear header pressure. The effect of changing the rear header pressure is apparently a function of the flow rate and tube power. In general, increasing the rear pressure increases the instability temperature. This can be seen from the following curves:

FIGURE 30 - EFFECT OF REAR HEADER PRESSURES - LOW TUBE POWER

FIGURE 31 - EFFECT OF REAR HEADER PRESSURE - HIGH TUBE POWERS

At low tube powers, all increases in rear header pressure increases the instability temperature. At high tube powers, and high flow rates the instability temperature is the same at several different rear header pressures. Thus, in Figure 31, the instability flow rate, W_a , is the same for rear pressures from 10 - 50 psi. Thus, operation at a 10 psi rear pressure would be about as safe as at 50 psi. As the rear pressure is increased further, the instability flow rate decreases further, such as W_b . Increasing the rear header pressure also decreases the tube and pile flow rates, such as from X to Y. Thus, an optimum rear header pressure should exist which will permit the highest allowable tube and pile power.

E. Present Status of Instability Limits

Instability limits depend upon tube flow rate. The Panellit gages measure only the venturi or orifice pressures, so that if a cone screen becomes plugged a false flow rate is indicated. Thus, to be safe, it has been assumed that actual tube flow rates are 10% less than indicated, and the operating temperature limits have been calculated accordingly. In some of the piles, however, large mesh cone screens have been installed and this 10% safety factor has been eliminated.

DECLASSIFIED

- 15 -

It is believed that some of the experimental data from which the instability temperatures were calculated are conservative. At the present time, all of the instability data are being re-evaluated for tube powers up to approximately 1100 kw and rear header pressures up to 70 psig. With these more accurate data it is anticipated that it will be possible to remove some of the existing conservatism and operate at higher tube outlet temperatures.

The approximate operating limits for the cases of small mesh and large mesh cone screens are shown in the following table:

TABLE 1
PRESENT OPERATING INSTABILITY LIMITS

Pile	Rear Header Pressure	Flow Rate	Allowable Outlet Temperatures	
			Small Cone Screens	Large Cone Screens
B,D,DR,F,H	20	20	102	110
	20	30	111	118
C,K	20	40	106	108
	20	50	111	113

For the old piles, tube outlet temperatures in the order of 120 - 125 C are required to attain a bulk outlet water temperature of approximately 100 C. For operation above 100 C, methods must be devised for removal of the steam which could be generated. This consideration, in addition to steam loss and a tube power surge, must be studied before operation at higher temperatures are permissible.

F. Future Limits and Associated Problems

Pile operation at temperatures greater than indicated in Table 1 can certainly be expected. For the preceding limits, a "G" factor of about 0.85 was assumed. This factor can be improved in many cases if the low trip can be relaxed.

Relaxation of the low trip will require studies to determine whether the high trip will effect a shutdown following cone screen plugging in sufficient time to prevent slug damage. Studies on the plugging characteristics of large mesh cone screens will also be required.

It might also be feasible to relax the high trip limit so that effectively the "G" factor approaches 1.0. If so, then the only limit will be how close to the instability temperature the tube can actually be operated. This will be determined by (a) how effectively the outlet temperatures can be controlled from a physics or hot-spot standpoint, (b) whether the pile can be scrambled in sufficient time to prevent melting if a power surge occurs which results in unstable flow conditions and (c) effects from electrical and steam power failures. Flow monitoring devices more sensitive than the Panellit pressure gages might be required for operation at these higher tube powers.

As mentioned previously, an increase of the rear header pressure will also increase the operating instability limit. Based on the above considerations and the increased flow rates after completion of CG-558, the anticipated operating temperatures and tube powers will be approximately as shown in Table 2.

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TABLE 2
ANTICIPATED FUTURE INSTABILITY OPERATING LIMITS

<u>Pile</u>	<u>Tube Flow Rate-gpm</u>	<u>Outlet Tube Temperature - °C</u>	<u>Tube Power - kw</u>	<u>Rear Header Pressure - psig</u>
B,D,DR,F,H	41	158	1600	100 - 150
C	49	145	1750	75 - 100
K	56	145	2000	75 - 100

It can be seen that the allowable temperatures at C and K Piles are less than at the old piles. It may be possible to increase these limits by placing restricting orifices in the outlet fittings at the C and K Piles. This and other methods will be studied.

Several operating factors which affect the conditions for adequate slug cooling must be considered before it will be possible to raise the outlet temperatures to the values as shown in Table 2. These are listed and briefly discussed below.

a. Power Surges or Local Power Excursions

A large increase in tube power causes the Panellit pressure to increase. Preliminary studies have shown that it might be possible to scram the pile in time to prevent slug melting if a tube power surge occurs. Additional studies will be made with the full scale mock-up equipment to determine if the Panellit gage does provide adequate protection for power surges. If the Panellit gages will not scram the pile in time to prevent melting, then it might be necessary to utilize thermocouples to provide the required safety or protection. Perhaps one thermocouple for each 25 tubes would be adequate.

b. Steam Power Failures

When a steam power failure occurs, the front header pressure decreases extremely rapidly and the pile is scrammed within 3 - 4 seconds, thus reducing the tube powers. However, during this period, unstable flow conditions may be established in the tubes. Experimental tests must be run to determine how serious this problem actually is at higher tube powers.

c. Electrical Power Failure

When an electrical failure occurs, the front header pressure decreases relatively slowly because of the flywheels on the electrical pumps. Also the pile is scrammed within a few seconds, reducing the tube powers so that unstable flow probably will not result. Here again, experimental tests must be run to determine the seriousness of the problem.

d. Boiling in the Outlet Fittings

At present boiling occurs in the outlet Parker fittings with no apparent adverse effects. At sufficiently high tube powers the boiling region will move back into the rear pigtail and approach the outlet nozzle. This boiling will increase the pressure drop across the rear fittings such that boiling will not occur within the tube. At the C, H and K Piles, the thermocouples are located on the rear crossheader fitting, so that if boiling occurs erroneous tube powers will be indicated. Thus, it might be necessary to re-locate the thermocouple positions at those piles for operation at higher tube powers. The thermocouples at B, D, F and DR Piles are satisfactory since they are located on the rear nozzles. For the same reason, it will be necessary to relocate the thermocouple which measure the bulk outlet water tempera-

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tures, At present it is impossible to measure accurately bulk outlet temperatures which exceed 100 C.

G. Effluent Piping Limits

For future pile operation, the bulk outlet water temperature may approach 130 - 140 C. Pressurization of the piping will be required to permit these temperatures. The capabilities of the piping to withstand these higher temperatures and pressures are doubtful and must be determined. If the piping will cause a limit to pile operation, or if the piping seriously affects pile cooling, then it might be necessary to install better piping.

If the piles were operated at bulk outlet temperatures in excess of 100 C, large volumes of steam would be generated at atmospheric pressure. The disposal of this radioactive steam may become a major problem. Several methods have been suggested, (a) use the steam to generate electricity, (b) remove the steam through large ducts and vent it to the atmosphere away from the operating area and (c) inject cold water into the rear piping so that no steam will be formed. A study must be made of this problem to determine the most practical solution.

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