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DR REACTOR BULK TEMPERATURE PROGRAM

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DR REACTOR BULK TEMPERATURE PROGRAMI. BASIS AND JUSTIFICATION

The present bulk temperature limit is based upon the assumptions:

1. Reactor effluent temperature excursions into the boiling region may cause effluent system damage, personnel injury, and/or loss of continuity of reactor operation.
- * 2. The deleterious effects will increase markedly with increases in the degree of the temperature surge above the boiling point.
3. The frequency of the temperature surges decreases very rapidly with increasing surge magnitude.
4. And finally, the value of production is such that it will pay for all costs associated with permitting the highest expected surges to cause bulk surges only moderately above saturation. The approximate value of 1°C increase in bulk temperature is \$170,000 per reactor year, neglecting any increase in other operating costs.

The bases for these assumptions is presented in a study report⁽¹⁾ and the present bulk limit specification is also documented.⁽²⁾⁽³⁾

Because this is based upon a considerable amount of information unconfirmed in detail by experimental data, a program has been developed for both improving our knowledge of this problem and for increasing the reactor power levels and production.⁽⁴⁾⁽⁵⁾

-
1. HW-51327, "Preliminary Analysis of Bulk Outlet Water Temperatures," May 8, 1957, S. S. Jones.
 2. HW-52793, "Reactor Bulk Outlet Temperature Limits," March 6, 1958, S. S. Jones.
 3. HW-46000, B, D, DR, F, H, & K, "Process Standard, Reactor 2.3-1, November 14, 1958.
 4. HW-52382, "Analysis of Reactor Water Piping, Statement of Problem, and Suggested Solutions," September 6, 1957, K. L. Bergman.
 5. HW-55801, "Bulk Outlet Temperature Limits and Increased Reactor Power Levels," June 13, 1958, S. S. Jones.

As noted in an earlier document, (5) the attainment of this bulk temperature increase will require the combined efforts of many different IPD groups. This report outlines a detailed program for achieving an improved bulk temperature limit and suggests a tentative schedule of work responsibility and completion date.

II. SUMMARY AND CONCLUSIONS

This report presents a program for obtaining increased bulk outlet temperatures at the DR-Reactor in FY-1960. There are seven basic parts:

(1) Instrumentation of the reactor, (2) Determining experimentally the magnitude of bulk temperature surges, (3) Obtaining prototypical reactor data and comparing with model studies, (4) Making boiling studies on the model, (5) Making special theoretical studies pertinent to this bulk problem, (6) Operating the DR-Reactor in the boiling region under transient conditions, and finally (7) Operating at higher bulk outlet temperatures continuously.

A general outline is presented followed by detailed recommendations for the instrumentation testing and special studies needed for this program. This report serves to recognize the many facets of the problem and to establish clear lines of responsibility and action for its solution. Closely coordinated and timely action by the several groups involved will permit determination of the maximum acceptable bulk outlet temperature at DR-Reactor by May, 1960.

III. OVER-ALL PROGRAM

A general over-all program was recommended in the earlier report on this subject.⁽⁴⁾ However, it is in order to up-date this to the DR reactor and the current conditions. The following general program is recommended, a good portion of which is already in progress.*

A. Laboratory Studies

1. Crossheader Mock-up

*Not
done*

Experimental studies have been made of the effects of high temperature high velocity flow from simulated reactor tubes into a model of a portion of a rear crossheader. Although these tests did not cover as severe a range of operation as is expected in the reactor, the results showed no sign of cavitation erosion. A report of this testing has been prepared by D. F. Bolender.

2. Downcomer Model

*Not
complete*

A model of the DR effluent system from the rear risers at the top crossheaders to the retention basin has been fabricated at the Albright Hydraulic Laboratory at Pullman, Washington. This model will be used to check proposed effluent system modifications and to study the effects of bulk boiling in the effluent system.

B. DR Reactor Instrumentation and Modifications

1. Instrumentation

a. Pressure and Temperature

Two important parameters associated with the variations in effluent flow and power level are the temperature and pressure at significant points in the system. A series of such points have been selected and this instrumentation has been installed

*See Table V, page 40, for Unit responsibility.

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Done

on both the prototype and the model. In addition, motion pictures will be obtained of the front riser pressures in the 105-DR control room.

Partially Done

b. Strain, Vibration, and Motion Measurements

In addition to determining the effect of operating conditions upon the coolant, it will also be very important to measure the effect of these changes in coolant temperature, pressure, and quality (weight per cent steam plus air) upon the piping structure. To do this, a rather complete instrumentation coverage will be required of the effluent system. This will include strain, vibration, and relative motion measurements of significant piping components.

Done

2. Reactor Effluent Piping Modifications

Work is already under way to modify the DR downcomers as shown in Design change No. 263. ⁽⁷⁾ This modification will involve sieving the trays, removing the vent lines, and cutting a weir in each tray I-beam.

c. Reactor and Model Testing

1. Verification of Bulk Temperature Surges

The verification of the present status of our bulk limit involves two reactor tests and the study of the following characteristics of the reactor system.

done

a. The theoretical rate and extent of reactor power increase

following the worst credible and the most probable rod withdrawal or poison discharge incident.

7. Design Change No. 263, "Modifications to DR Downcomer," L. B. Brinkman, February 2, 1959.

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- b. The effect of a difference in side-to-side tube outlet
temperature distribution upon the flow split between the
two risers.

*must
Calc.
more data
prob.
req.*

The reactor tests involve measuring the transient-temperature changes following a power level surge and following a BPA outage at reduced reactor power conditions. These tests can be performed in an essentially safe manner and at the same time yield valuable reactor transient data never before obtained.

done

Physics studies should be made in order to obtain a recorded and more complete picture of the reactor transients to be expected from either the sudden discharge of a poison column or the inadvertent withdrawal of one or perhaps two control rods. . The flow studies will indicate the actual enthalpy split between the near and far rear risers when there is a side-to-side mal-distribution of the reactivity such as occurs during reactor "turn-around".

These experimental temperature surge results, modified to indicate the results expected from similar events occurring at full reactor power level, may be used to establish more accurate bulk temperature surge values for the different postulated transient events.

*to
do*

At the same time, a study of the scram reports by L. J. Newell should lead to more accurate frequency values for these events.

These values should be combined in the manner proposed in the original bulk temperature limit study⁽¹⁾ to give the costs of operation at various bulk outlet temperatures. And finally, these

1. Op. Cit.

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costs should be combined with rupture costs, etc., to obtain the optimum reactor power level based upon the values of increased production less the costs associated with obtaining this at higher power level and outlet temperatures.

It is important to emphasize that the results of this program may not lead directly to increased bulk outlet temperatures and production. However, they will certainly lead to a great increase in our knowledge of the problem; to a considerable increase in reactor safety, and it should point the way toward the changes in reactor instrumentation, piping, or operation that will be required to circumvent this bulk temperature limit.

Two methods of reducing the magnitude of bulk temperature surges that do not involve changes in poison columns or control rods have been proposed.⁽⁸⁾ An additional part of this program will involve a study of these methods to determine their benefits and indicate which, if any, should be used to increase bulk temperature limits.

2. DR Effluent System Model Studies

A downcomer model testing program has been developed at the Albright Hydraulic Laboratory, Washington State College, that has given good similitude results for a model of the F-Downcomer.⁽⁹⁾⁽¹⁰⁾

-
8. HW-55486, "Proposal for Improved Control of Bulk Effluent Temperature Surges," March 25, 1958, S. S. Jones.
 9. GEH-24162, "Hydraulic Model Studies of 100F-Downcomer and Effluent System," R. L. Albright Hydraulic Laboratory, Washington State College, E. R. Tinney, November 15, 1958.
 10. GEH-24522, "Hydraulic Model Studies, 100-DR and 100-F Downcomers", R. L. Albright Hydraulic Lab., Washington State College, C. C. Lomax and L. J. Mathews, August 31, 1959.

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*Improper
approach
section*

A model of the DR-Downcomer has been fabricated that includes the cross-over line and the two rear risers down to the top crossheader. This model and the DR reactor effluent system will be instrumented pressure and temperature-wise as nearly identical as possible in order to obtain the best picture of their similitude. Once this is established, the model will then be used to study the effects of steady state and transient boiling. If these results indicate that no instabilities exist and that no excessive flow or pressure surges will occur then the third phase studies can be started.

3. Increased Bulk Outlet Temperature

The increases in bulk outlet temperature that may result from the first phase studies, i.e., bulk temperature surge verification, do not negate the need for the latter studies. They may reduce their urgency, but it will still be very important to determine the nature of boiling in this downcomer effluent system. A fundamental part of this bulk limit is the assumption of severe damage at bulk temperatures in the range of 105 to 115°C and minor damage at 100 to 103°C. It is expected that the model studies can be made to throw considerable light upon this fundamental assumption. And finally, the actual attainment of boiling in the effluent system during a carefully limited transient condition will yield strain gage and motion measurements that will determine the validity of these damage assumptions.

*open
to question*

D. Analytical Studies

There are a number of analytical studies that should be made to support this program. They are needed:

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- a. To assist in the verification or revision of the present bulk limits.
- b. To determine the degree of similitude of the model and the prototype.
- c. To ensure that the proposed reactor tests have an adequate margin of safety and will yield results capable of application to a revision of the bulk temperature limits.

The range of these studies is considerable and covers various fields of endeavor. The details of these studies together with the unit involved are presented in the following sections.

1. Reactor Bulk Temperature Transients Caused by Reactivity Changes

The original analysis of reactivity effects was somewhat skimpy and no report was presented showing the details upon which Figure A-IV-I in HW-51327 was based.⁽¹⁾ Therefore, the following program of theoretical investigation has been requested of Pile Physics.

- a. Determine the rate and amount of power level increase for the most probable and worst credible case of:

- Pone*
- (1) Sudden discharge of a poison column.
 - (2) Inadvertent withdrawal of one or two horizontal control rods.

- ?
- b. Estimate quantitatively the reactivity and power level differences that would exist between a reactor power level surge from equilibrium level and the test I-A which approximates this condition.

- ?
- c. Estimate quantitatively the reactivity and power level differences that would exist between a reactor power failure scram from full level and the simulation test I-B.

These studies have a high priority since they apply to the initial phases of the bulk temperature increase program. These studies will be used to re-evaluate the bulk limit and to indicate the range of the testing conditions to be used on the model.

2. Rear Riser Temperature Distributions

Preliminary discussions with Pile Physics have indicated that a considerable unbalance can exist in the heat split to the near and far side of the reactor. This would cause a corresponding split in the heat flow to the rear risers and a significant difference between the two risers' bulk outlet temperatures.

The first phase of this study involves obtaining experimental values for this temperature deviation between the two risers. This can be done by taking temperature maps at significant times (including the most normal condition of reactor operation and the most severe) and having IBM combine this temperature information along with their latest tube flow data to obtain the riser bulk outlet temperatures.

According to the formula:

$$\bar{t}_{RN} = t_i + \frac{2\sum_N (t_{on} - t_i)G_n}{G_T} \quad (1)$$

Where $\bar{t}_{RN}$ = average near riser temperature - °C

t_{on} = individual tube outlet temperature - °C

t_i = inlet temperature

G_n = individual tube flow of all tubes to near side of reactor center-line

G_T = total reactor flow

and Σ_N indicates the sum of the product of $G\Delta t$ for all the tubes on the near side of the reactor center-line.

A similar equation would apply to the far riser. This determination of the indicated rear riser bulk temperatures, neglecting any differences in riser flow, should be done by Process Engineering.

The second phase of this study involves the determination of the effect of different riser temperatures upon the reactor flow split between the two risers. This should include the effect upon the flow split of one riser temperature exceeding saturation.

Thermal Hydraulics has already performed a portion of this riser cross-over analysis and they will be requested to determine this temperature distortion effect upon the flow split between the two rear risers.

This problem may be a very significant one since the lowest pressure point in the effluent system is probably in the cross-over line that connects the two risers with the downcomer. If boiling in the cross-over cannot be tolerated, then the reactor will be riser temperature limited, rather than downcomer and for any side-to-side heat flux distortion would have a riser bulk temperature limit below that in the downcomer. Experimental verification of this riser temperature distortion should be obtained after the temperature elements, shown in Figure 1, have been installed. (These are numbered AT-1 to AT-4.)

3. Model - Prototype Similitude

The DR Downcomer model is considered to be an important adjunct to this bulk temperature increase program. However, the usefulness

FIGURE 1
PRESSURE AND TEMPERATURE INSTRUMENTATION
FOR DR REACTOR BULK TEMPERATURE TEST

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of this experimental device will vary directly with the degree of similitude that is obtained between the model and the prototype. True similitude is impossible because of conflicting scale ratios for various flow parameters. Therefore, Thermal Hydraulics has been asked to study this similitude problem both now and as this program progresses and more results are obtained from both model and prototype. It will be important to maintain our testing conditions so that the model is as close to the prototype as possible. Where this is not possible, the model results should be interpreted in a manner that will ensure less severe results on the prototype.

4. Study of Temperature Control Suppression of Bulk Temperature Surges

Three methods have been proposed for permitting increased bulk outlet temperatures by operating the reactors with added instrumentation or in such a manner that the magnitude and frequency of the severe bulk temperature surges can be greatly reduced.⁽⁸⁾⁽⁹⁾

A study should be made of the instrument aspects of these methods to evaluate their cost and operability. Consequently, Instrument Development Unit will be requested to evaluate the instrument aspects of these two systems. This will involve the following:

a. Use of Present Zone Temperature Monitor

Twenty-five zone temperature monitor tubes, evenly spaced about the reactor central zone will be reset periodically to maintain their trip point $\leq X^{\circ}\text{C}$ above their operating temperature. Whenever this trip temperature is exceeded by

8. Op. Cit.

9. Op. Cit.

three or more of these tubes within a 0.5 second period, then a #1 scram will immediately occur. This system will thereby catch power level surges or slow flow decays before they reach the normal trip points and reduce the magnitude of the bulk temperature surge. The value of this proposed system depends upon how small the value of X can be without causing unnecessary scrams, what the total time constant* is of these tube outlet temperature elements, and whether Operations can manage the intermittent resetting of each of these 25 zone temperature monitors. The increase in bulk outlet temperatures that can be effected for various values of X and θ_t , the temperature element total sensitivity (period) is given in a recent report.⁽¹¹⁾ This method, although possessing the merit of simplicity and speed of application has several handicaps. It will require a great deal of supervision and operator time and will not achieve its goal unless low enough values of X and total temperature system period can be achieved without causing unnecessary reactor scrams.

b. Development of Proposed Bulk Zone Temperature Monitor System

This proposed system⁽⁸⁾ consists of 5 to 16 tube outlet temperatures evenly spaced in the reactor central zone. These

8. Op. Cit.

11. HW-60854, "Feasibility Study of Proposal of R. L. Call for Effluent Bulk Temperature Monitoring System," June 23, 1959, K. W. Norwood.

* Time for the total temperature measuring system to reach to 63% of a step change in the coolant temperature.

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contain a dummy charge downstream of the active zone made up of two perfs and the rest solids, except for the aluminum perf, over the pigtail port. The temperature elements in these 16 tubes will all be calibrated and have a time constant ≤ 1.5 seconds. The temperature signal will be supplied to a passive scanning system in a scattered fashion as indicated in Figure 2. These will be scanned rapidly about twice a second. Whenever four or more temperatures show a temperature increase of more than 1°C per 0.5 second the reactor will automatically be scrambled. Such a system will automatically eliminate any slow bulk temperature excursions and will considerably reduce the magnitude of excursion produced by poison discharge, too rapid rod withdrawal, etc.

Instrument Development will be requested to study the development of such a system on the basis of just the few reactor tubes, rather than the several hundred tubes being worked into the K-Zone Temperature Monitor system. **

5. Study of Other Means of Bulk Temperature Surge Suppression

In addition to modifications in the use of the outlet temperature elements there are several other changes that will reduce the magnitude of some of the bulk temperature surges. For instance, causing an immediate reactor scram upon the loss of power to any

* All reactor tests in this program will be covered by the usual Production Test procedure.

** According to preliminary work by A. G. Dunbar, K. W. Norwood, and R. Sherrard, it may also be possible to use the power rate meter for this purpose.

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Figure 2

Bulk Temperature Surge Supression.

of the 190 Annex process pumps instead of depending upon a Panellit trip will reduce the bulk temperature surge from a 4 to 8°C value down to a 1 to 2°C value. This change was recommended in an earlier report⁽²⁾ and has been adopted at most reactors.

In the same manner power level surges caused by inadvertent poison discharge or control rod removal can be reduced by limiting the size of the poison column and reducing the withdrawal speed of the control rods. An analysis of this condition was made and the results of this analysis are presented in a recent document.⁽¹²⁾ This proposed change requires the least time to place into effect and a negligible amount of instrumentation.

From an over-all point of view, however, it may be more desirable to use the temperature surge limiting system rather than the poison and control rod limitations; or it may be desirable to use both. A study of both systems should be made in order to establish the system that will be most useful to reactor operations while achieving an optimum reduction in the frequency and magnitude of the bulk temperature surges.

IV. DETAILED TEST PREPARATIONS

A. DR Effluent System Instrumentation

1. Pressures

In addition to the pressure transducer instrumentation shown in Figure 1 the front risers pressures are to be instrumented with

2. Op. Cit.

12. HW-62113, "Method of Controlling Reactor Power Surges to Permit a Bulk Outlet Temperature Limit Increase," September 29, 1959, J. F. Music.

a Heise gage mounted in a special stand prepared for the B-C trip-out test. Their arrangement is shown in Figure 3.

These stands are equipped with signal lights and timer for photographic measurement of the rate of change of riser pressure. This will provide us with a fairly accurate means of monitoring the reactor flow during these testing periods.

2. Temperatures

Four bulk outlet temperature elements are to be installed, two in each of the rear risers, and a temperature element should be installed in the bottom of the effluent line just downstream from the downcomer. The location of this instrumentation is also shown in Figure 1. In addition, five reactor tubes, one in the center and one near each corner are to be charged with an 80 per cent solid rod dummy section and their outlet temperatures supplied to the multichannel temperature recorder.

I&E
Probe →

3. Downcomer Water Level

Probably the most significant level in the downcomer (the unperforated trays tend to build up a level on each tray) is that at the top of the downcomer. This is because of the very low strength at this location. (13)(14) Therefore, a level gage is to be installed as shown in Figure 1, #Cp-1, to indicate top-of-downcomer water level. It is also important because of the drastic change in pressure variation with flow that occurs as

13. R. F. Jimenez to H. W. Heacock DO-0280, "Downcomer Pressurization Study," April 15, 1957.
14. HW-56697, "Stress Analysis of Bulk Effluent System Components in B and C Reactors," O. E. Adams, Jr., July 10, 1958.

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Figure 3 - Heise Gage Connections to Measure Front Riser Transient Flow

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soon as the effluent system is running full rather than with free fall from each tray.

4. Strain Gages

There are two general areas of strain gage instrumentation:

- a. Reactor rear face
- b. Downcomer

The strain gages should be installed on the rear face as shown in Figure 4. These may be of the conventional type protected with epoxy cement. The gages should be installed by the Mechanical Development Unit of Equipment Development Sub-section, according to detailed locations supplied by Reactor Modification Design. The general location of these gages is shown in Figure 4.

Improper installation

The downcomer strain gages might well be the new weld-on strain gage units that will definitely withstand the temperature and flow conditions anticipated within the downcomer. These gages, or some other type which has received prior service testing, will be installed in the downcomer by the Material Development Unit of Equipment Development Sub-section. The general location of these gages is shown in Figure 5. The specific details of their location will be provided by the Reactor Engineering Unit.

5. Miscellaneous Stress Indication Measurements

In addition to the measurement of strain at various critical points in the effluent system, the following types of stress indication measurements should be made:

- a. Vibration
- b. Relative motion

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FIGURE 4
REAR FACE INSTRUMENTATION
FOR BULK INCREASE PROGRAM

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Plan View of Top

End View of Tray

Instrument Tray
#7 in Same Manner

FIGURE #5
DOWNCOMER STRAIN
GAGE INSTRUMENTATION

*Development Gage

There may be locations such as the downcomer approach elbow and the highest flow crossheaders where the specific strains will not be unduly large, but where vibration effects produced by excessive coolant turbulence may result in a piping failure. Therefore, some exploration of the frequency and magnitude of these vibrations should be made.

Because of the difficulty of locating strain gages at the points of maximum strain combined with the high costs of their installation, it will be desirable to monitor gross relative motion of significant portions of the effluent system.

*Not
done*

Suggested locations for motion and stress instrumentation location on the rear face piping has been given by Bergman.⁽³⁾ This report should be reviewed and appropriate instrumentation prepared to monitor the stress conditions of this effluent piping during the testing program and thereafter. A tentative location of this miscellaneous instrumentation is presented in Figure 4.

B. DR Effluent System Modification

1. Initial Changes

As noted earlier, a design change⁽⁷⁾ has been approved for the modification of the DR-Downcomers. This change has been completed in the near downcomer and is in progress in the far. Because of the scope of this change and the limited data then available, it was decided to make this change in two steps in

3. Op. Cit.

7. Op. Cit.

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the DR far downcomer and to obtain model verification of these step changes. Accordingly the following changes were completed in the far downcomer by September 1959.

- a. Remove all vent lines from inside the downcomer.
- b. Cut out sixteen 8-inch holes in the top cascade tray and cut a weir in the I-beam of this tray as shown in the Design Change No. 263.
- c. Install stiffening channel irons around the downcomer walls at each tray.
- d. Install the test instrumentation shown in Figures 1, 4, and 5.

2. Completion of Design Change No. 263

The delay in this modification work permitted model evaluation of this change and consequently the Design Change was completed. It was modified to the extent of reducing the hole sizes in the bottom two trays.

3. Miscellaneous Modifications

During the course of this testing program it may become apparent that certain effluent system modifications or maintenance are required. The problem may be amenable to maintenance repair, with indications that such repairs will not be required too frequently. On the other hand, it may be obvious that certain system modifications will be required to handle the problem. Consequently, both maintenance and reactor modification forces must maintain a close survey of the test results of this bulk program.

V. DETAILED TESTING PROGRAM

Reactor Testing Program

This program of bulk temperature testing has three phases. The first phase involves experimental confirmation of some of the basic assumptions that were made in developing the present bulk temperature limits. The second phase involves model studies to establish the nature of boiling in the effluent system. If model studies are encouraging, some reduced flow, downcomer boiling should be attempted. The third phase involves actual continuous operation of the reactor at increased bulk water temperatures.

A. Phase I - Reactor Confirmation

We do not have any actual measurements of reactor bulk temperature surges during a transient condition. The reactor bulk temperature limit is based to a large degree upon the actuality of such temperature surges. Therefore, experimental confirmation, in a manner that will yield safe reactor operation, should be obtained.

1. Test I-A - DR Reactor Power Level Surge

- a. Just prior to the scheduled shutdown of the DR reactor, the power level should be reduced by 30 per cent as rapidly as possible by the insertion of a poison column* and resetting of control rods. It should be held at the new level for 15 minutes.
- b. During this 15 minute period the Beckmans should be reset to 115 per cent of the new power level and a careful watch should be maintained of any panellit gages near the trip point.

* This poison column should be designed by Reactor Physics to have a Δh value of about 15 to 20 in.

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- c. At the end of this period, the high-speed equipment should be started at the count of 3 on a count-down from 10 to 0 and at 0 time, the special poison column* should be flush discharged.
- d. The resulting surge in reactor power level from 70 per cent of level should be scrammed by any one of four procedures:
- (1) Beckman trip at 1.12×70 or 78 per cent of original level.
 - (2) Manual VSR trip when the bulk outlet temperature, as measured by the new rear riser instrumentation, reaches 80°C or above.
 - (3) Manual VSR trip as soon as the power level recorder indicates a reactor power level 80 per cent or more of the original full level operation.
 - (4) Manual VSR trip after 20 seconds if the reactor has not yet scrammed.
- e. High speed recordings should be obtained of the piping instrumentation during the course of this test from 3 seconds before the 0 count to about 100 seconds afterwards. Before and after this period, intermittent readings should be obtained of the same data. The instruments to be recorded are those indicated in Figures 1, 3, 4, and 5.
- f. During the course of this test, the 190 steam turbines should be accelerated and ready to give full back-up flow protection to the reactor.

* This poison column should be designed by Reactor Physics to have a Δh value of about 15 to 20 in.

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This test should provide us with a safe means of determining the bulk temperature response to a transient increase in power level. It will permit both a more accurate evaluation of the present bulk temperature limit and will provide improved source data for use in the DR downcomer model studies.

2. Test I-B - BPA Failure Temperature Transient Effects

- Done*
- a. At the completion of the same shutdown that was started with Test I-A, i.e., at least 30 hours down, start up the reactor by raising the power level as rapidly as permitted by Process Standards to 50 per cent of normal equilibrium level. Hold the level here for 15 minutes.
 - b. Check all instrumentation and obtain an initial set of "steady state" readings between 10 and 15 minutes after reaching this level. Then count down from 10 to 0 starting the high speed recorders at the count of 3 and tripping out the electrical power to the DR process pumps at the count of 0.
 - c. Record the temperature and flow down to the stable flow obtained from 8 steam pumps that were previously accelerated and all set to take over the pumping load.
 - d. When steady flow conditions are reached, stop the recorders and obtain a final set of test data.

In this test, the same instrumentation will be required as for Test I. Although imposing a BPA outage on an operating reactor is inherently dangerous, it is minimized by going only to 50% of level and operating for only 15 minutes before a scram. Under these conditions, the moderator will be relatively cool and the heat from the decay of fission products will decay down to that

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from the previous extended full level operation which had decayed for 30 hours. The graphite heating, which is normally 6 per cent, would be negligible; and the delayed fission heating would be 1/2 the normal value and would become negligible in 200 seconds.

During this time, the flow provided by the flywheel decay would be more than ample during the initial transient. Following this the back-up flow provided by any one of three sources:

- a. Steam turbine pumps,
- b. High tanks, and
- c. Export lines

would also supply adequate reactor cooling at the end of the flywheel decay period. This test should give us about half of the expected bulk temperature surge for a BPA failure at full level, which is adequate for accurate measurement of the actual temperature transient.

These two tests complete the Phase I testing program unless their results indicate additional tests required to adequately cover the experimental approach to this important problem. Their results will be of great value both to the determination of revised bulk temperature limits and to nuclear safety studies. These results will also be used to more accurately interpret the results of the model tests underway at Pullman.

B. Phase II - Model and Prototype Confirmation

The purpose of this DR model is to obtain a system that will provide reasonable similitude between model and prototype for present operating conditions and to proceed from this established reference point to

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investigate the effects of boiling. This will involve a study of a number of important parameters. Since the model cannot be used directly for stress or strain measurements, the emphasis will be upon the determination of the degree of pressure and flow stability that exists for various extremes of model operation. Or conversely, to measure the amount of flow and pressure surging that occurs under the different test conditions. The parameters to be investigated at various flow and outlet temperature conditions are:

- a. Effect of slow power level increase into the boiling region.
- b. Effect of slow decrease in system flow to cause bulk temperature boiling.
- c. Effect of one riser slow increase in power or decrease in flow to cause boiling in one riser only.
- d. Effect of rapid decrease in flow to cause bulk boiling.
 - (1) In one riser
 - (2) In both risers

The instrumentation shown in Figure 1 should be installed plus additional instruments considered desirable by the Laboratory. After preliminary checking and testing, the program just outlined should be performed. The test data should include that noted in Tables I and II, while a brief outline of the actual test procedures is submitted below:

1. Reactor Tests

After the completion of the Design Change #263 and the installation of the test instrumentation shown in Tables I, II, III, and IV, the following reactor test should be made:

- a. With the reactor down and the instrumentation checked and calibrated, increase the reactor flow step-wise as indicated

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TABLE I

INSTRUMENTAL REQUIREMENTS FOR PRODUCTION TEST I-A

<u>Type</u>	<u>Location</u>	<u>Instrument</u>	<u>No.</u>	<u>Measurement Function</u>
Pressure	Front Risers	Heise gage & camera	---	Reactor flow
"	Rear Cross-over and Risers	Pres. Transducer	AP-xx BP-xx	Approach to boiling
"	Top-of-Downcomer	" "	CP-xx	"
"	Down. Trays	" "	DP-xx LP-xx	Dynamic pressure surges
"	Down. Walls	" "		" "
"	Down. Effluent	" "	MF-xx	Line Pres.
Temp.	Rear Risers	RTD elements & high speed recorder	AI-xx	Bulk Effluent Temp.
"	Down. Effluent	" "	MI-xx	Total Bulk Temp.
"	5 High level high exposure tube outlet temp.	" "	T _C -xx	Tube outlet temp. response
Neutron Flux	Reactor	Beckman	#2	Power level surge

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TABLE II

LOCATION OF BULK TEMPERATURE TEST STRAIN GAGES

<u>Number</u>	<u>General Location</u>	<u>General Function</u>	<u>Installed By</u>	<u>Results Analyzed by</u>
A	Rear Crossheaders at the risers	Riser to Crossheader weld stress	Material Dev. Unit Equip. Dev. Subsection	React. Mod. Unit Proc. Des. Sub-section
B-1*	Riser connection to cross-over	Riser conn. stresses	" "	" "
B-2*	Cross-over expansion sections	Expansion joint stresses	" "	" "
C	Downcomer approach elbow	Elbow loop and weld stress	" "	" "
D	Downcomer lid.	Weld stresses	" "	" "
E**	Downcomer trays	" "	" "	" "
F**	Lower downcomer walls	" "	" "	" "

* Not actually installed

** Installation not completed for first testing program.

TABLE III

REACTOR AND MODEL TESTS IN THE MODEL SIMILITUDE PROGRAM

Test No.	Test Type	Test Location	Prototype Flow gpm	Bulk Outlet Temps.						
				Near Riser			Far Riser			Bulk
				#1	#2	Avg	#3	#4	Avg	
II-A-1	Prototypical (Cold H ₂ O)	Reactor	20,000	}	Shutdown Conditions*					
-2		Model	20,000							
-3		Reactor	40,000							
		Model	40,000							
-4		Reactor	60,000							
		Model	60,000							
-5		Reactor	80,000							
	Model	80,000								
	Model	90,000								
		100,000								
II-A-2	Prototypical (Increasing power)	Reactor	80,000	Corresponding to ~750 MW						
		Model	60,000	63			63			63
		Model	80,000	55			55			55
		Model	100,000	48			48			48
		Reactor	80,000	Corresponding to ~1000 MW						
		Model	60,000	83			83			83
		Model	80,000	67			67			67
		Model	100,000	58			58			58
		Reactor	80,000	Corresponding to ~1500 MW						
		Model	80,000	91			91			91
		Model	100,000	77			77			77
		II-A-3	Prototypical (Side distortion)	Model	60,000	83			98	
	60,000			98			83			
	80,000			83			98			
	80,000			98			83			
	100,000			83			98			
	100,000			98			83			

* All tests at cold water temperature

** Assuming inlet H₂O temperature = 20°C

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Present results suggest delaying this test

TABLE IV

MODEL TESTS TO BE COVERED IN THE MODEL BOILING PROGRAM*

Test No.	Test Type	Prototype Flow In gpm		Bulk Outlet Temps.					
				Near Riser			Far Riser		
				#1	#2	Avg	#3	#4	Bulk
I-B-1	Boiling (Steady state)	60,000	Initial			95			95
			Final			120			120
2			Initial			90			95
			Final			110			115
3		80,000	Initial			100			95
			Final			120			115
4			Initial			95			95
			Final			120			120
5		100,000	Initial*			90			95
			Final			110			115
6			Initial*			95			95
			Final			115			115
7			Initial			100			95
			Final			115			108
I-C-1	Boiling (Transient Flow Decrease)	60,000	Initial			95			95
		51,000	Final			109			109
2		60,000	Initial			90			94
		51,000	Final			104			108
3		60,000	Initial			98			94
		51,000	Final			113			108
4		80,000	Initial			95			95
		68,000	Final			109			109
5		80,000	Initial			90			94
		68,000	Final			104			108
6		100,000	Initial			95			95
		85,000	Final			109			109
7		100,000	Initial			90			94
		85,000	Final			104			108
I-D-1	Boiling** (Transient Power Increase)	60,000	Initial			95			95
			Final			105			105
2			Initial			98			94
			Final			108			104
3		80,000	Initial			95			95
			Final			105			105
4			Initial			98			104
			Final			108			95
5		100,000	Initial			95			95
			Final			105			105
6			Initial			98			94
			Final			108			104

* For any significant indicated model or prototype changes, many of these tests will be repeated.

** These tests will not be run under the present contract and will only be run if considered necessary after the completion of I-B and I-C.

in Table I. Take a full compliment of instrument readings at each step and proceed to the next.

- b. After reaching full flow, increase the reactor power-level step-wise as shown in Table I, again taking full instrumentation readings at each step.

This information should provide a good basis for obtaining good prototype data for comparison with the model, and the data are obtained in such a manner that no Production Test should be required.

2. Downcomer Model Studies (Albrook Hydraulic Laboratory)

A general test procedure⁽¹⁵⁾ has been submitted to Roy E. Tinney, Director of the laboratory, and they are proceeding with their model design and construction.

a. Test A - Confirmation of Prototype Results

- (1) With tests instrumentation installed as shown in Figure 1 and with additional static pressure taps installed in the downcomer to obtain the pressure gradient, perform the tests shown in Table I for prototype model confirmation.
- (2) Upon completion of these and other tests considered desirable by the testing personnel, a review will be made to determine what model changes, if any, are indicated to improve both the non-boiling and boiling similitude of the proposed boiling tests.

15. H. W. Heacock to R. E. Tinney, "Model of 100-DR Downcomer Design Development and Research Contract DDR-41 Supplemental Contract #2," June 10, 1959.

b. Test B - Steady State Boiling

- (1) Upon completion of any required model modification and instrumentation changes, perform the steady state boiling tests.
- (2) Include in this testing program the specific tests noted in Table II. These tests are to be run by starting at the conditions noted in the table as "original" and raising the heat exchanger outlet temperature, at constant pump speed, at a rate of about 1°C per minute until the specified temperature limit is reached. The test should be continued at these specified elevated conditions for 15 to 60 minutes.
- (3) The results of these steady-state boiling tests will be studied and interpreted to give expected operation of the prototype under boiling conditions. If it is concluded that steady-state boiling presents no model hazards, the transients testing program will be started.

c. Test C - Transient Boiling - Sudden Flow Decrease

- (1) With the high speed instrumentation installed, calibrated, and running, suddenly reduce the flow to a pre-set value as shown in Table II. This flow change should occur within 2 seconds.
- (2) Maintain the new conditions of temperature and flow for about 15 minutes.

d. Test D - Transient Boiling - Sudden Power Increase*

- (1) With the model at specified flows and temperature, the

* This test requires considerable model revision and will only be run if considered necessary after completing all other tests.

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instruments running and calibrated, open the steam supply to the heat exchangers to give a 10 per cent increase in the power level. The riser outlet temperatures should be increased at a rate of 1.5°C per second until the desired bulk outlet temperature is obtained.

- (2) Maintain the new conditions of flow and temperature for 15 minutes.
- (3) Record pressures and temperatures periodically after reaching stable flow conditions during this <15 minute period. After the indicated testing series is completed, along with any additional tests considered necessary, a review should be made of the test results to determine their significance with respect to reactor flow loss transients and power surge transients.

C. Phase III - Actual Increased Bulk Temperature Operation

If the results of the Phase I and the Phase II studies indicate that bulk temperature excursions can occur without pressure surging or other dangerous condition, then Phase III tests should be conducted. Otherwise we should proceed in the direction of effluent system pressurization. Assuming the former condition, the Phase III tests are as follows:

1. Test III-A - Transient Boiling in the Effluent System

- a. After a normal reactor shutdown, raise the power level as quickly as permitted for a "cold" startup to give a 93°C bulk outlet temperature.
- b. Hold the reactor at this level for 15 minutes and obtain a set of initial test readings.

- c. Have the flow from two of the 7 pumps adjusted so that the loss of one will cause only a 5 per cent reduction in reactor flow, and after a routine count-down, trip the power to these pumps.* After 10 seconds, manually scram the reactor with the VSR's in case it has not already scrambled.
- d. During this period and for 30 more seconds thereafter, record the pressures, strains, and temperatures listed in Table II on high speed recorders.

Depending upon the results of this test, it should be repeated at 95, 97, and 98°C bulk outlet temperature with each test being made as soon after startup from a ~30 hour shutdown as possible.

These tests will serve as the most important confirmation of the desired increases in bulk outlet temperature. They are the only tests in which boiling in the prototype will purposely occur.

2. Test III-B - Production Test Operation at Increased Bulk

The final step in this program will be to increase the bulk to the highest safe value and maintain continuous operation at this new level. The test will serve to determine whether any long term effects exist that may diminish the level to which the effluent temperature should be increased because of corrosion, slug rupture, effluent piping fatigue failure, or other long term feature that makes the higher bulk level unfeasible.

VI. RESPONSIBILITIES

Any program of this magnitude will require the participation of many different groups. Establishing a clear interrelation between these groups will do much to facilitate the accomplishment of this IPD goal.

* This should be checked during reactor shutdown including the flow decay transient when the power to this pump motor is tripped.

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This report presents a tentative program and assignment of responsibilities. This is presented in the hope that it will aid in clear establishment by the various units of their different responsibilities in this program. This recommended program participation is presented in Table V.

VII. TENTATIVE SCHEDULES AND COSTS

In order to make this program more than a gleam in an engineer's eye it is important to establish a schedule for its accomplishment. A tentative schedule is presented in Table VI. This has been reviewed by the Units concerned and general agreement reached concerning responsibilities and schedules.

VIII. ACKNOWLEDGEMENTS

The author wishes to express his thanks and appreciation to M. H. Schack for his very helpful handling of the liaison for the DR Downcomer Model Studies; and to O. E. Adams, Jr. for his handling of the stress aspects of this study.

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Reactor Engineering Unit
Research & Engineering Section
IRRADIATION PROCESSING DEPARTMENT

Approved:

R. E. Trumble, Supervisor
Reactor Engineering Unit
Research & Engineering Section
IRRADIATION PROCESSING DEPARTMENT

TABLE V

GENERAL BULK TEMPERATURE PROGRAM RESPONSIBILITIES

<u>Testing Program</u>	<u>Unit</u>	<u>Responsibility</u>
1. Reactor Instrumentation	Maint. Engr.	Install required test instrumentation.
	Material Dev.	Proof-test and install strain and motion instrumentation on DR reactor rear face piping and downcomer.
	Process Engr.	Maintain liaison between the concerned units and insure the completion of the required test instrumentation in time for the scheduled tests.
	Reactor Engr.	Specify location of pressure, temperature, and downcomer strain gage locations.
	Reactor. Mod. Des.	Specify location of strain gage and motion instrumentation on rear face.
	Reactor Opers.	Schedule necessary operating or shutdown time required for the installation of the required test instrumentation.
	React. Plant Engr.	Develop, have installed, and calibrate pressure, temperature and miscellaneous instrumentation on DR-effluent system.
	Instrument Dev.	Determine pump speed decay and power ratemeter change after each tripout test.
2. Reactor Effluent Modifications	Maint. Engr.	Make DR far downcomer modifications as agreed upon by RE, RMD, and WPUO.

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Testing Program

Unit

Responsibility

Process Engr. Provide liaison with concerned units and insure scheduled completion of effluent modifications.

Reactor Engr. Consult with RMD and WPUO and agree upon effluent system modifications.

React. Mod. Des. Consult with RE and WPUO and agree upon effluent system modifications.

Reactor Opers. Schedule required effluent system modifications and provide required time and manpower.

Water Plant & Utilities Oper. Consult with RE and RMD and agree upon effluent system modifications.

3. Prototype Data

Power Operations Provide stepwise increases in flow as per Table and directions from Reactor Operations.

Process Engr. Supervise obtaining reactor prototypical data.

Reactor Engr. Define required prototypical data and interpret test results.

React. Mod. Des. Provide the Albroom Laboratory with the prototypical data obtained in these tests.

React. Plant Engr. Obtain test data on the high speed instrumentation and report results in terms of transposed data from the recorder charts.

4. Model Studies

Albroom Hydraulic Lab.
Washington State
College 1) Design and construct DR downcomer model and evaluate similitude of model and prototype.

2) Conduct boiling studies in model.

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Testing Program

Unit

Responsibility

	Reactor Engr.	Interpret results of model studies and define reactor testing program on the basis of model results.
	React. Mod. Des.	Maintain liaison between Albroom Lab. and Hanford.
	React. Plant Engr.	Provide special instrumentation.
5. Reactor Tests - Phases I and III	Power Operations	Provide detailed test procedures for Power personnel and supply required reactor flows with maximum assurance of reactor flow back-up.
	Process Engr.	Obtain production test approvals, provide pre-test liaison with respect to instrumentation and test scheduling, and assist in test procedures.
	Reactor Engr.	Prepare required Production Tests; direct test operation, interpret test results and prepare final reports.
	React. Mod. Des.	Evaluate reactor effluent system modifications indicated by test results.
6. Special Studies	Instr. Dev.	Evaluate quantitatively the total response time and trip frequency of the three proposed methods limiting bulk outlet temperature surges.
	Pile Physics	1) Evaluate the theoretical temperature or power level changes for sudden poison discharges, or control rod withdrawals.
	Reactor Engr.	2) Estimate degree of approach of verification tests (Phase I - A&B) to actual reactor conditions for a full level power surge or BPA outage.

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Testing Program

Unit

Responsibility

Process Analysis

Combine the revised increased bulk outlet temperature costs with the other power and temperature dependent costs to obtain new reactor power levels.

Reactor Engr.

Determine revised values of costs associated with high bulk outlet temperatures, based upon the special study and test results obtained in this program.

Thermal Hydraulics

- 1) Make theoretical studies of the similitude between the model and prototype.
- 2) Determine theoretical near and far riser flow split for experimentally determined temperature split.
- 3) Miscellaneous theoretical studies in support of this program.

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TABLE VI
TENTATIVE TIME AND COST SCHEDULE FOR
THE DR BULK PROGRAM

<u>Unit</u>	<u>Job Description</u>	<u>Test</u>	<u>Compl. Date</u>	<u>Cost</u>
1. Albrook Hyd. Lab.	1. Design and construct DR-model from top rear crossheader to retention basin.		Sept. 15	20,000
	2. Compare DR Downcomer operation under Phase 1 Downcomer modification with the operation under complete Design Change #263 modification.	IIB	Oct. 15	5,000
	3. Make DR Downcomer model boiling studies and determine steady state and transient boiling effects on system static and dynamic pressures and upon the water level at the top of the downcomer.	IIB	Dec. 30	7,200
	4. Explore boiling and two-phase flow model similitude factors.		May 60	2,800
2. Instr. Dev.	1. Study two bulk-temperature monitoring concepts and submit proposal for limiting bulk temp. surges by monitoring selected tube outlet temps.		Mar. 60	5,000
	2. Install bulk temperature zone monitoring instr.		July 60	50,000
	3. Monitor pump speed decay in tripout tests.	IB	Oct. 23	---
3. Mat. Dev.	1. Purchase, install, & calibrate strain gages on downcomer.	IA,B IIIA,B	Oct. 16	3,000
	2. Develop and install strain gages inside Downcomer.	IIIA,B	Feb. 20	1,000
	3. Design, install, & calibrate strain gages & miscellaneous motion instr. equipment on DR rear face piping.	IA,B IIIA,B	Oct. 16	2,000 500
4. Maint. Engr.	1. Perform DR Downcomer modification according to stages established by RMD, RE, and WP & UD.		Sept. 28	2,000
	2. Install pressure and temperature equipment, required for this program, in the DR far downcomer and cross-over lines.		Oct. 15	500

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<u>Unit</u>	<u>Job Description</u>	<u>Test</u>	<u>Compl. Date</u>	<u>Cost</u>
5. Pile Physics	1. Determine theoretically most probable and worst credible rate and degree of power rise for a poison discharge or rod withdrawal. 2. Calculate theoretically worst side-to-side heat split at highest power level.		Sept. 15	
6. Power Oper.	1. Prepare detailed test procedures for Power operation.	IA, B IA IIIA, B	Sept. 15 Sept. 15 Feb. 25	
7. Process Anal.	1. Revised bulk limits for DR. 2. Revised bulk limits for all old reactors.		April 15 May 30	
8. Process Engr.	1. Prepare detailed test procedures for 105 operation. 2. Have Production tests approved. 3. Complete prototype tests for model verification. 4. Complete determination of side-to-side heat split. 5. Review PT results with RE and RMD and determine advisability of proceeding with program. 6. Assist in Production Test performance.	IA, B IIIA IA, B IIA IIIA, B IIA IA, B IIA, B IA, B IIA IIIA IIIB	Oct. 2 Feb. 25 Sept. 28 Sept. 28 Feb. 20 Oct. 16 Nov. 20 Jan. 30 Nov. 23 " Mar. 15 June 30	
9. Reactor Engr.	1. Determine location of pressure, temp., strain gage and misc. instrumentation on DR cross-over and downcomer. 2. Prepare Production Tests. 3. Review results of model tests DR Downcomer and determine with RMD and WP & UE on final DR modification. 4. Conduct DR React. Phase I Production Tests. 5. Review Production Test, results, the theo. physics bulk temperature surge calculations, and the model studies and prepare revised bulk limit specifications.	IA, B IIIA, B IA, B IA, B IB, IIA IA	Sept. 15 Jan. 30 Sept. 15 Oct. 5 Oct. 23 Nov. 23	

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<u>Unit</u>	<u>Job Description</u>	<u>Test</u>	<u>Compl. Date</u>	<u>Cost</u>
	6. Maintain program review with PE & RMD & decide on bulk temperature increases.	IIIA, B	Jan 30	
	7. Conduct Phase III Production Tests and interpret results.	IIIA IIIB	March 15 June 30	
10. React. Mod. Des.	1. Determine rear face piping instrumentation and location.	IA, B IIIA, B	Sept. 15	
	2. Have Albroom Lab. complete preliminary non-boiling studies of DR Downcomer model, including Phases I and II of Design Change #263.	IIB	Oct. 10	5,000
	3. Have Albroom Lab. make any indicated model changes and conduct boiling studies on model.	IIB	Jan 25	7,200
	4. Maintain review of bulk program with PE & RE and decide whether to proceed with bulk temperature increase program.	IIIA, B	Jan 30	
11. Reactor Oper.	1. Schedule time and manpower for completion of DR effluent system instrumentation.		Oct. 15	
	2. Schedule start-up test data by October 16.	IIA	Oct. 16	
	3. Schedule Phase I Production Tests.	IB IA	Oct. 23 Nov. 23	
	4. Schedule time and manpower for Phase III tests during period.	IIIA IIIB	March 15 June 30	
12. Reactor Plant Engr.	1. Complete installation and calibration of pressure and temperature test equipment on DR rear face and downcomer.	IA, B IIA	Oct. 16	6,000
	2. Obtain prototype test data.	IIA	Oct. 16	
	3. Obtain verification test data.	IA, B	Nov. 23	
	4. Obtain prototype boiling data.	IIIA	March 15	
13. Thermal Hyd.	1. Determine similitude between model and prototype both for non-boiling and boiling conditions.		Jan 15	
	2. Determine ther. effect of side-to-side reactor heat distortion upon the riser flow split.		Dec. 20, '60	
	3. Misc. effluent system thermal hyd. problems.			
14. Water Plant & Utilities Engr.	1. Inspect and maintain DR effluent system and downcomer.			
	2. Determine with R&E and RMD upon downcomer modifications.			

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