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MEMORANDUM

HW # 281

This document consists of 15 pages [redacted]

9-47

To: J.B. Miles

From: J. Marshall J.M.

OPERATING STANDARDS — STUDY OF START UP — PHYSICS MEASUREMENTS

As a starting point for planning the physics measurements to be made during the start up of the pile, this memorandum describes a procedure for each of three cases, a large poisoned pile, running at power with a small unpoisoned pile but making physics measurements with the large pile before going to power, and a similar case except that the physics measurements on the large pile are done after running with power on the small pile. This memorandum should by no means be taken as a final proposal. It has resulted in uncovering shortcomings in instrumentation which have been covered in other memoranda. Estimates of the time required for the physics measurements are given. These will furnish you with a basis for discussion with the Operating Supervision to estimate the total time required for each step.

The three alternative schemes for loading and calibrating the first Hanford pile are outlined below.

Case I. Here it is assumed that plenty of jacketed metal is available at start up time. Also it is assumed that we are willing to load the pile full to 2004 tubes and to run it flattened from the start. In this method rectangular loading is used because it is simple and takes less time.

The steps used in Case I are outlined here. They are given in more detail later in the memorandum.

1. Load the pile dry to critical load (prismatic loading).
2. Load dry to 2004 tubes, test safety rods against dry pile.
3. Admit water to pile tubes.
4. Poison to about operating conditions.
5. Thermal coefficient measurement.
6. Calibration of control rods.
7. Operate pile.

The operations in Case I would be used with practically no change for a 1500 tube pile.

Case II. In Case II it is assumed that plenty of slugs are available but that it is decided to run a smaller pile of about 750 tubes first to check corrosion problems

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before going to the large pile. It is also assumed that the large pile will be run with only 1500 tubes.

1. Load pile dry to critical load (cylindrical loading).
2. Load to 1500 tubes dry, testing safety rods.
3. Admit water to pile tubes.
4. Poison to dead pile.
5. Discharge poison and outer tubes to 750 tube pile.
6. Thermal coefficient measurement.
7. Calibrate control rods.
8. Operate small pile at power.
9. Reload outer tubes of pile, repoison, calibrate control rods.
10. Operate pile at power.

Case III. This is the case where only enough canned metal is available at start up time to make a pile of 750 tubes. When metal becomes available later the pile would be charged to 1500 tubes with a flattened central region.

1. Load pile dry to critical load (cylindrical loading).
2. Load dry to 750 tubes.
3. Admit water to pile tubes.
4. Thermal coefficient measurement.
5. Calibration of control rods.
6. Operate 750 tube pile at power.
7. Recharge 750 tubes with new metal, dry the pile.
8. I. Charge to 1500 tubes, add water, poison and calibrate pile using continuous neutron measurement monitoring.
   II. Same as 8 I using foils to measure neutrons.

Case I. If plenty of jacketed metal is available at start up and it is desired to run a full pile the following might be the start up procedure.

1. Load the pile dry keeping it always the shape of a rectangular parallelopiped. First load 4 horizontal rows of tubes. This will leave the pile with a horigontal strip of live lattive 4 rows high and 46 rows long.

Expose an indium foil at the center of the pile and record the number of counts per minute for an infinitely long irradiation. The foil should be exposed for about 20 minutes in the central shim rod hole. There is room enough between the shim rod and the thimble to insert a foil holder.

While the first indium foil is being counted another two rows of tubes should be loaded. One row should be above and one below the first four. This will keep the leaded lattive about centered. Expose another indium foil and count it.

Continue in this way exposing indium foils after the following numbers of rows of tubes have been charged: 4,6,7,8,9,10,11,12. A plot should be started after the second foil has been irradiated of A^2/I against A^2. A is the side length of a cubical load having the same reactivity as the load in question. It can be calculated from the relationship $3/A^2 = \frac{1}{a^2} + \frac{1}{b^2} + \frac{1}{c^2}$ where a,b, and c are the lengths of the sides of the loaded lattice.

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I is the calculated initial activity of a foil irradiated for a few minutes. This plot will give a continuous descending curve which intersects the axis at the value of A^2 corresponding to the critical load. In this way the critical load can be predicted accurately before it is reached. The critical load should be reached when 13 rows have been charged.

The charging should be done with all rods out of the pile. This will save considerable time and is not at all dangerous provided that an adequate watch is kept of the neutron intensity at all times. For this purpose there should be two BF_3 proportional counters in the pile from the start of charging. These counters could be inserted in one of the central tubes of the pile. They should be connected to separate scaling and recording circuits and a continuous record should be kept of their counting rates as a function of the numbers of tubes charged. This data can be plotted to give essentially the same information as is given by the indium foils.

In addition to the proportional counters there should be in the pile an ionization chamber connected to a galvanometer. This system should have a sensitivity of about 1 cm deflection per watt of power. A careful watch of this galvanometer should be kept as the pile approaches the critical load. If the intensity starts to rise one of the control rods should be driven in to hold it constant.

An ionisation chamber should also be connected to the safety circuits so that if the intensity rises above 10 kw the pile is scrammed. Both of the chambers could be inserted in the 3½" test holes in the pile.

2. After the critical load has been reached two or three more tubes should be charged. Then the rods should be withdrawn and the rising period of the pile measured. The period can be measured conveniently using a proportional counter to detect the neutrons. This procedure can be repeated once or twice more, each time charging two more tubes. From the formula relating excess reactivity with period, values of the excess reactivity in inhours can be calculated. From these an extrapolation will give a value of the critical load.

Now the pile should be loaded until it is completely filled. The safety rods should be adjusted continuously so that it remains in a critical state or approximately so. In this way a plot of number of safety rods versus number of tubes loaded can be obtained. The safety rods should be inserted in a definite pattern. One possible pattern would be to start at the top of the safety rod controls and proceed to the right and downward as in reading a book.

Because of shadowing effects the safety rods are less effective when used together than they would be if they were used widely separated from each other. When all the rods are dropped together it is estimated that they decrease k by about 4%. This means that the average rod has an effect of about .14% in k. If one rod having this effect were retracted from a pile at critical positon, the pile would rise with a period of about 45 seconds. The maximum effect that a safety rod might have would be of the order of .4% in k. Retracting one safety rod with this effectiveness would give the pile a period of 8 seconds.

The safety rods are motor driven at about 1 ft per second. While this is a little fast for a regulating rod it should not be too difficult to regulate the pile using safeties instead of regulating rods. The operator will be kept busy but he should be able to handle the situation. If the pile should start to rise faster than he had expected he is in an excellent position to drop in as many safeties as he sees fit.

There is a chance that the safety rods will be insufficient to hold the dry unpoisoned full pile. In this case poison should be introduced at the center to hold the pile as the last tubes are loaded.

3. Now water should be let into the tubes and a measurement should be made of the critical state of the pile in terms of the number of safety rods necessary to hold it. If the water is let in slowly the operator should be able to hold the pile critical or nearly so as the water goes in.

4. At this point the safety rods should be replaced with control and shim rods so that more accurate measurements can be made of the effect of poisoning. Perhaps 4 rods will be necessary to hold the pile.

Poison should now be introduced into the pile. Tubes should be poisoned with loads of jacketed lead-cadmium slugs spaced so that about one tube in 80 is poisoned. The poisoning should start at the center and extend outward. As the poison tubes are charged, the rods should be adjusted so that the pile intensity remains constant. These tubes might be charged with the charging machine so that the k of the pile is varied slowly enough for measurements to be made. A record should be kept of the poison tubes charged against the control and shim rod setting. Poisoning should continue until the pile is held by one control rod all the way in.

5. A thermal coefficient should now be measured. One of the control rods should first be calibrated over a short range by displacing it a few inches from the critical position and measuring the period of the pile. This can be done at two positions. A critical position should now be measured. Then the inlet water should be heated a few degrees so that the pile can warm up. When the pile has been raised to a uniform temperature, the critical position can be measured again. From the difference between the critical positions the thermal coefficient can be calculated. The effects due to metal temperature and graphite temperature can be separated during the cooling of the pile back to cold water temperature. This can be done because the metal is cooled much more rapidly than the graphite. It will only be possible, however, if the hot water temperature is at least 30°C above the cold water temperature. This is because a fairly large effect is necessary to make the rapid measurements required.

From the measured temperature coefficient the critical position of the pile under power can be calculated approximately. The loading should now be adjusted so that about 1/3 of a control rod is necessary to hold the running pile.

6. The control rods should now be calibrated. This can best be done by the following procedure. Bring the pile to critical position using one control rod to hold the pile if possible. Now pull this rod out a few inches and measure the period of the pile. Pull it out farther and measure the period again. No periods should be used that are smaller than about 30 seconds for the sake of accuracy. Now leave the rod in the last position and insert the other control rod until the pile is critical again. Repeat the procedure until the first rod is all the way out of the pile. In this way both rods have been calibrated from the critical position outward.

The rods can be calibrated for positions farther in than critical by observing the equilibrium counting rate of a counter in the pile. The counting rate should be inversely proportional to 1-k where k is the reproduction factor.

7. The pile is now ready for operation. Observation should be made of the power distribution among the water tubes so that the poisoning can be adjusted to get optimum power output.

Time Consumed for Various Steps.

Case I.

1. Measurements during dry loading to critical load. 2 hours extra time for irradiation

2. Measure 3 periods, 20 minutes each. 1 hour
   Load to 2004 tubes. This step takes time necessary to load about 1600 tubes
   Time required unknown
3. Find critical state with water in pile. 1 hour
4. Replace safeties with shim rods to hold pile critical. ½ hour
   Poison to operating condition. This step takes the time necessary to charge no more than 10 tubes one slug at a time. No extra time is required for measurements
5. Thermal coefficient. 5 hours
6. Calibrate control rods. 4 hours
7. ---

CASE II. If plenty of metal is available at start up time, but still it is decided to run a small pile for a time first to study corrosion and radiation effects on structural materials, it might be desirable to load 1500 tubes first and then discharge them according to the following procedure:

1. a. Load pile with no water in it. One of the central tubes should be left empty so that two BF_3 counters can be inserted. These two counters will be connected with separate scaling circuits and recorders. All rods are to be out of pile. The loading is to start at the center and is to be kept approximately cylindrical in shape.

1.b. When 100 tubes have been loaded an indium foil is to be given an irradiation at the center of the pile. This can best be done in the central shim rod hole. A foil holder can be inserted as there is 1/4" of clearance between the shim rod and the top of the hold. After a 10 or 15 minute irradiation this foil is to be counted with a β counter and the activity it would have had if the irradiation time had been infinite, computed.

This procedure is to be repeated after the following numbers of tubes have been loaded: 100, 150, 200, 240, 270, 300, and as often as is deemed advisable after that. The irradiation time will be adjusted to give a convenient counting rate.

A plot should be made of the reciprocal of the activity of these indium foils against the numbers of tubes loaded. As the critical load is approached the equilibrium activity of the pile gets larger and larger until it becomes infinite at $k = 1$. The plot mentioned above will give a continuous descending curve which will intersect the axis at the critical load.

A continuous record is also to be kept of the counting rate of the BF_3 counters as a function of the number of tubes charged. The counters will give essentially the same information as that obtained with the indium foils.

The measurements in (b) are possible because the pile with k less than 1 acts as an amplifier of the neutrons naturally present from spontaneous fission.

1.c. During the loading there should be in the pile an ionization chamber sensitive to neutrons and capable of giving a galvanometer a deflection of about 1 cm. when the pile is at the power level of one watt. This chamber could be inserted in one of the 3½" test holes.

There should also be in the pile a chamber connected to the safety circuits so that the rods will be driven in if the power rises above about 10 kw.

As the critical load is approached a close watch of the neutron intensity as indicated by the ion chamber and the counters must be kept. As soon as the galvanometer shows a deflection the pile should be stabilized with one of the control rods.

2.a. The pile is now approximately at the critical load. Load two more tubes. Now let the pile rise in intensity with the rods all out and measure the period. This can best be done with the proportional counters. The excess reactivity of the pile can be calculated from the formula.

$$\delta ih = \frac{54}{\tau} + \frac{33}{\tau + 0.7} + \frac{1139}{\tau + 6.5} + \frac{1793}{\tau + 34} + \frac{585}{\tau + 83}$$

Load two more stringers and repeat the measurement. Load two more and repeat. The measurements in this section quite accurately indicate the critical load of the pile by extrapolation back to zero excess reactivity.

2.b. Now load the pile farther keeping it as near the critical state as is possible by using the safety rods as control rods. This should be quite easy with the system of control that the safety rods will have. Keep a record of the number of safety rods necessary as a function of the number of tubes charged. This should continue until 1500 tubes are charged.

3. Now water should be let into the pile and a measurement should be made of the critical state of the pile in terms of the number of safety rods necessary to hold it. If the water is let in slowly the operator should be able to hold the pile critical or nearly so as the water goes in.

4.a. At this point the safety rods should be replaced with control and shim rods so that more accurate measurements can be made of the effect of poisoning. Perhaps 2 shim rods and 2 control rods will be necessary to hold the pile.

4.b. Poison should then be introduced into the pile. Stringers should be poisoned with jacketed lead cadmium slugs on a square lattice, 9 tubes on a side. The poisoning should start at the center and extend outward. As the poison tubes are charged, the rods should be adjusted so that pile intensity remain constant. A record should be kept of the poison tubes charged against the control rod and shim rod setting. Poisoning should continue until the rods are withdrawn completely from the pile.

5. The outer 750 tubes and the poisoned tubes should now be discharged. The pile should be brought to such a state that one control rod most of the way in can hold the pile critical. The outer 750 tubes should be recharged with dummy slugs having the same outer dimensions as the standard slugs.

6. A thermal coefficient should now be measured. One of the control rods should first be calibrated over a short range by displacing it a few inches from critical position and measuring the period of the pile. This can be done at two positions. A critical position should now be measured. Then the inlet water should be heated a few degrees so that the pile can warm up. When the pile is raised to a uniform temperature the critical position can be measured again. From the difference of critical position the thermal coefficient can be calculated. The effects due to metal temperature and graphite temperature can be separated during the cooling of the pile back to cold water temperature. This can be done because the metal is cooled much more rapidly than the graphite.

From the measured temperature coefficient the critical position of the pile under power can be calculated approximately. The loading should now be adjusted so that about 1/3of a control rod is necessary to hold the running pile.

7. The control rods should now be calibrated. This can best be done by the following procedure. Bring the pile to critical position using one control rod to hold the pile if possible. Now pull this rod out a few inches and measure the period of the pile. Pull it out farther and measure the period again.

no period should be used that is smaller than about 30 seconds for the sake of accuracy. Now leave the rod in the last position and insert the other control rod until the pile is critical again. Repeat the procedure until the first rod is all the way out of the pile. In this way both rods have been calibrated from the critical position outward.

The rods can be calibrated for positions farther in than critical by observing the equilibrium counting rate of a counter in the pile. The counting rate should be inversely proportional to 1-k where k is the reproduction factor.

8. The pile is now ready for operation. It should be brought as rapidly as is consistent with safety to such a power (about 100KW) that the central tubes heat the water to about 60°C. Presumably the pile will be operated at this power until a satisfactory answer has been obtained as to corrosion problems and so forth.

9. Now it will probably be desirable to load the pile to 1500 tubes and to poison the center so that the power output can be raised. The amount of poison necessary can be predicted approximately, from the observed change of critical position of the rods in the small pile during operation and from the poisoning data obtained in 4. After the pile is reloaded and poisoned the control rods can be calibrated by observing the period of the pile for various control rod settings at powers of the order of 1000 kw.

10. The pile would now be ready for operation at high power. Observations should be made of the power distribution in the water tubes so that the poisoning can be adjusted to get optimum power output.

Time Consumed for Various Steps. Case II.

1. Load dry to critical load. Foil measurements

Tubes loaded	Irradiate	Measure
100	15 min.	Simultaneous with loading
150	"	
200	"	
250	"	
300	10 min.	
330	"	
350	"	
360	"	
370	"	
380	"	
	2 hours extra time for irradiation	

2. a. Measure 3 periods - 20 minutes each. 1 hour
   b. Load to 1500 tubes
      This step takes the time necessary to load about 1100 tubes. Time require unknown
3. Find critical state with water in pile. 1 hour
4. a. Replace safeties with shim rods to hold pile critical. ½ hour
   b. Poison to dead pile. This step takes the time necessary to charge no more than 10 tubes. No extra time is required for measurements.
5. Modify charge to 750 tubes cylindrical pile. This step takes the time necessary to charge 760 tubes. Time required unknown.
6. Thermal coefficient. 1 hour
7. Calibrate control rods. 4 hours
8. Operate pile for one month.
9. Load pile to 1500 tubes and poison calibrate. 1 hour
   Calibrate control rods. 4 hours

Case III. Only enough metal is available at start up to make a pile of 750 tubes and later metal for 1500 tubes is available.

1.a. Load pile with no water in it. One of the central tubes should be left empty so that two BF_3 counters can be inserted. These two counters will be connected to separate scaling circuits and recorders. All rods are to be out of pile. The loading is to start at the center and is to be kept approximately cylindrical in shape.

1.b. When 100 tubes have been loaded an indium foil is to be given an irradition at the center of the pile. This can best be done in the central shim rod hole. A foil holder can be inserted as there is 1/4" of clearance between the shim rod and the top of the hole. After a 10 or 15 minute irradiation this foil is to be counted with a β counter and the activity it would have had if the irradiation time had been infinite, computed.

This procedure is to be repeated after the following numbers of tubes have been loaded: 100, 150, 200, 240, 270, and 300 and as often as is deemed advisable after that. The irradiation time will be adjusted to give a convenient counting rate.

A plot should be made of the reciprocal of the activity of these indium foils against the number of tubes loaded. As the critical load is approached the equilibrium activity of the pile gets larger and larger until it becomes infinite at k = 1. The plot mentioned above will give a continuous descending curve which will intersect the axis at the critical load.

A continuous record is also to be kept of the counting rate of the BF_3 counters as a function of the number of tubes charged. The counters will give essentially the same information as that obtained with the indium foils.

The measurements in (b) are possible because the pile with k less than 1 acts as an amplifier of the neutrons naturally present from spontaneous fission.

1.c. During the loading there should be in the pile an ionization chamber sensitive to neutrons and capable of giving a galvanometer a deflection of about 1 cm when the pile is at a power level of one watt. This chamber could be inserted in one of the 3½" test holes.

There should also be in the pile a chamber connected with the safety circuits so that the rods will be driven in if the power rises above about 10 kw.

As the critical load is approached a close watch of the neutron intensity as indicated by the ion chamber and the counters must be kept. As soon as the galvanometer shows a deflection the pile should be stabilized with one of the control rods.

2.a. The pile is now approximately at the critical load. Load two more tubes. Now let the pile rise in intensity with the rods all out and measure the period. This can best be done with the proportional counters. The excess reactivity of the pile can be calculated from the formula:

$$\delta ih = \frac{54}{T} + \frac{33}{T+0.7} + \frac{1139}{T+6.5} + \frac{1793}{T+34} + \frac{585}{T+83}$$

Load two more stringers and repeat the measurement. Load two more and repeat. The measurements in this section quite accurately indicate the critical load of the pile by extrapolation back to zero excess reactivity.

2.b. Now load the pile farther keeping it as near the critical state as possible by using the safety rods as control rods. This should be quite easy with the system of control that the safety rods will have. Keep a record of the number of safety rods necessary as a function of the number of tubes charged. This should continue until 750 tubes have been charged.

2.c. The outside of the pile should now be loaded with dummy slugs having the same diameter as the standard slugs. The water orifices should be zoned so that the center 800 tubes get 24 g.p.m. each while the outer 700 get 16 g.p.m.

3. Now the water should be admitted to the pile. If the water is turned on fairly gradually the operator should be able to keep a critical position using the safety rods until the pile is critical with all tubes filled. With water in the tubes the pile should be critical with about one control rod all the way in. If this is not the case the loading should be adjusted to make it approximately true.

4. A thermal coefficient should now be measured. One of the control rods should first be calibrated over a short range by displacing it a few inches from critical position and measuring the period of the pile. This can be done at two positions. A critical position should now be measured. Then theinlet water should be heated a few degrees so that the pile can warm up. When the pile is raised to a uniform temperature the critical position can be measured again. From the difference of critical position the thermal coefficient can be calculated. The effects due to metal temperature and graphite temperature can be separated during the cooling of the pile back to cold water temperature. This can be done because the metal is cooled much more rapidly than the graphite.

From the measured temperature coefficient the critical position of the pile under power can be calculated approximately. The loading should now be adjusted so that about ½ of a control rod is necessary to hold the running pile.

5. The control rods should now be calibrated. This can best be done by the following procedure. Bring the pile to critical position using one control rod to hold the pile if possible. Now pull this rod out a few inches and measure the period of the pile. Pull it out farther and measure the period again. No periods should be used that are smaller than about 30 seconds for the sake of accuracy. Now leave the rod in the last position and insert the other control rod until the pile is critical again. Repeat the procedure until the first rod is all the way out of the pile. In this way both rods have been calibrated from the critical position outward.

The rods can be calibrated for positions farther in than critical by observing the equilibrium counting rate of a counter in the pile. The counting rate should be inversely proportional to 1-k where k is the reproduction factor.

6. The pile is now ready for operating. It should be brought as rapidly as is consistent with safety to such a power (about 100 MW) that the central tubes heat the water to about 60°C. Presumably the pile will be operated at this power for about a month or until enough metal is available to recharge the pile.

7. Now it will probably be desirable to load the pile to 1500 tubes so that the center can be flattened and the power output raised. In order to make the proposed measurements it will be essential that the pile be completely discharged. This is necessary so that the water can be drained to test the safety rods. The procedure will be the following:

Keep the water flowing at a reduced rate and replace all of the metal in the pile with new metal.

Now with the safety rods in, dry the pile. This can be done by removing the end caps. Perhaps it will be necessary to blow the water out with compressed air.

Now pull the safety rods out a few at a time using foils to measure activity. In this way the critical state of the pile can be found. The critical state can be fairly accurately predicted by the measurements in 2b.

8.I. There is a possibility that the induced radioactivity of materials in the pile will be so high that measurements of small neutron intensities with an ionization chamber or a counter will be impossible. It would be convenient at this stage to be able to measure neutron intensities corresponding to 100 watts of power. If the following procedure is carried out at powers much above 1 kilowatt the radiation intensities may be uncomfortably high. Let us assume that critical position can be measured at about 1 kilowatt.

Bring the pile to a critical position using the safety rods as regulating rods. Now charge with metal the outer 750 tubes that up to the present contained only dummy slugs. Keep the load approximately cylindrical. As each tube is charged adjust the safety rod position so that the power level remains constant. Keep a record of the number of safety rods necessary to hold the pile at various loads. The procedure should be followed until 1500 tubes are loaded. If it should turn out that the safety rods are insufficient to hold the pile, substitute poison slugs for metal slugs in the control stringers reloading one tube in 25.

Now water should be added to the pile. The pile should be brought to a critical state with the safeties, and poison should be introduced into stringers in the central zone until the pile can be held with one control rod all the way in.

The control rods should now be calibrated. This will be done in the same way as is outlined above for the small pile. It will not be necessary to measure a thermal coefficientas the thermal properties of the lattice will be already fairly well know from the small pile.

The pile is now ready for operation.

8. II. If it turns out that it is impossible to measure small neutron intensities in the presence of the background of the pile the loading will have to be done using foils to locate the critical state. This will be more time consuming. The procedure would be as follows:

In 2.b. the number of safety rods necessary to hold the dry 750 tube pile was measured. Insert 5 more safety rods than this number. Now irradiate indium foils and load as in Step 1.b. In this way the critical state can be predicted before it is reached. Before the critical load is reached insert 5 more safety rods. Repeat the above procedure. In this way a rough plot of the numbers of safeties necessary to hold various loads can be obtained. Proceed until the pile is loaded to 1500 tubes.

Now water should be added to the pile. The critical position can be found by retracting safety rods and irradiating indium foils until the critical number of rods can be predicted by extrapolation. Poisoning should now be added to the central zone. Periodically the safety rods should be retracted one by one and indium foils should be irradiated to find the critical state. This procedure can be followed until the critical state as above can be represented by one control rod all the way in!

Now the control rods can be calibrated as above except that now it will probably be necessary to operate at higher intensities. It should be perfectly alright to run the pile at several hundred kw. for this calibration.

Time Consumed for Verious Steps. Case III
1. Load dry to critical load
   Foil measurements

Tubes loaded	Irradiate	Measure
100	15 min.	Simultaneous with loading
150	"	
200	"	
250	"	
300	10 min.	
330	"	
350	"	
360	"	
370	"	
380	"	
	2 hours extra time for irradiation	

In this case with no pile background an ionization chamber can be used to indicate when intensity goes up.

2. Measure 3 periods —20 minutes each . 1 hour extra
3. Find critical position with water in small pile. 1 hour extra
4. Thermal coefficient. 5 hours
5. Control rod calibration. 4 hours
6. —
7. Dry the pile
   Find critical state. This has already been done in 1 and 2 so it should not take long using foils. 2 hours
8. I. Find critical state of full pile with safeties, water in tubes, no poison.
   2 hours Control rod calibration . 4 hours
   II. Load to 1500 tubes from 750 tube pile dry

Safeties	Tubes Loaded	Irradiate	Measure foil
5		15 min.	20 min. simultaneous loading
	10	"	" " " "
	10	"	" " " "
	1/3 way to critical	10 min.	20 min. hold loading
	1/2 way to critical	"	20
		extra time taken 2 hours	

Repeat this procedure until pile is loaded to 1500 tubes. It might be repeated five times. This would be 10 hours extra.

Add water to find critical state	4 hours	
Poison to best guess	4 hours	to get critical with shims
Calibrate control rods	4 hours	

This seems to indicate that 24 hours might be used up in case 8 b for measurements.

Step	Operation	Information obtained	Time: Operation	Time: Additional for measurements	Remarks
Case I					
1.	Load dry (prismatic) about 13 rows (600 tubes)	Dry critical load		2 hrs	Loading must be done anyway
2.	Measure periods with 2,4, and 6 tubes additional	Accurate dry critical load		1 hr	
3.	Load to 2004 tubes dry; hold pile critical with safeties (about 1400 tubes added)	Effectiveness of safety rods for worst possible case		none	Loading must be done anyway
3.	Let water in slowly	Safeties needed to hold full pile wet		none unless rate of water addition is slower than otherwise	Water must be put in anyway
4.	Replace safeties with shims	Comparison of safeties and shims		½ hour	Makes measurement in next step more significant
	Poison to operating condition approximately	Effectiveness of poisoning as measured by shims		none	Poisoning must be done anyway
5.	Heat pile	Temperature coefficient of reactivity		1 hr	To predict best poison pattern
6.	Calibrate control rods	Control rod calibration of full poisoned pile		4 hrs	Needed to follow poisoning changes
7.	Operate at power				

Step	Operation	Information obtained	Time: Operation	Time: Additional measurements	Remarks
Case II					
1.	Load dry in steps cylindrical (about 400 tubes)	Dry cylindrical load		2 hrs	Loading must be done anyway
2.(a)	Measure periods with 2,4, & 6 additional tubes	Accurate dry critical load		1 hr	
(b)	Load to 1500 tubes holding pile in critical state (about 1100 tubes added)	Effectiveness of safety rods for worst possible case		None	Unnecessary now, but desirable if 1500-tube pile is to be run later
3.	Put in water slowly	Safeties needed to hold 1500 tubes wet		None unless rate of water addition is slower than otherwise	Water must be put in anyway
4.(a)	Replace safeties with shims	Comparison of safeties and shims		½ hr	Makes measurements in next step more significant
(b)	Poison to dead pile (estimate less than 10 tubes poisoned) (1 slug at a time)	Effectiveness of poisoning as measured by shims Flattening obtainable (if a neutron traverse is made)		None	Will save time when later going to 1500 tubes
5.	Modify to 750 tubes (discharge 750 tubes)	A wet critical size could be got by discharging to 680 tubes		None	Must be done if 2 is done
6.	Heat pile (5° for uniform coeff.) (30° for cold metal hot graphite if done)	Temperature coefficient of reactivity		1 hr	Useful for predicting pile size
7.	Calibrate control rods	Control rod calibration small pile		4 hrs	Needed to follow poisoning changes
8.	Operate 4-6 weeks				

Step	Operation	Information obtained	Time: Operation	Time: Additional for measurements	Remarks
9.	Discharge & charge 1500 tubes & poison			None	
	Calibrate at 1000 kw	Control rod calibration large pile		4 hrs	Probably run at this level short time anyway
Case III 1.	Load dry in steps (cyclindrical) about 400 tubes	Dry critical load		2 hrs	Loading must be done anyway
2.(a)	Measure periods with 2,4,& 6 additional tubes	Accurate dry critical load		1 hr	
(b)	Load dry to 750 tubes holding pile in critical state with safeties	Effectiveness of safety rods		None	Loading must be done anyway
(c)	Load outside of pile with dummies	—		—	Necessary to restrict water flow in outer tubes
3.	Put in water slowly & adjust load	—		1 hr to find critical position	
4.	Heat pile	Temperature coefficient of reacting		1 hr	Useful for predicting best pile size
5.	Calibrate control rods	Control rod calibration small pile		4 hrs	Needed to follow poisoning changes
6.	Operate pile at power 4-6 weeks	—		—	

Step	Operation	Information obtained	Time: Operation	Time: Additional for measurements	Remarks
7.	Discharge & recharge small pile	—		—	Must be discharged so that water can be drained
	DRY the pile				Pile must be dried to test safety rods
	Measure critical state	Will indicate depoisoning or poisoning of graphite to a certain extent		2 hrs	Necessary for measurements in 8
8 I	Charge outside of pile keeping pile critical with safeties	Effectiveness of safeties for worst case		None	Pile must be charged anyway
	Add water to pile			None	Water must be added anyway
	Measure critical position	Effectiveness of safeties on wet pile		2 hrs	Necessary for subsequent step
	Poison center to operating state	Effectiveness of poison vs shim rods			Must be done to operate
	Calibrate control rods	Control rod calibration of large pile		4 hrs	Needed to follow poisoning changes
8 II	Alternate procedure to 8 I			about 24 hrs	Must be used if no sensitive neutron detector is available which will work in presence of gamma ray background