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PROPOSED PRODUCTION TEST
FOR REDUCING MINIMUM DOWNTIME

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PROPOSED PRODUCTION TEST FOR REDUCING MINIMUM DOWNTIME

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PROPOSED PRODUCTION TEST FOR REDUCING MINIMUM DOWNTIME

OBJECTIVE

The object of this P.T. is to evaluate the operational aspects of a proposed method for reducing minimum downtime. The excess xenon poisoning, which occurs during the first 32-38 hours after the shutdown of a reactor from present equilibrium levels, will be partially overridden by a central enriched zone whose added reactivity contribution would be compensated during normal operation by means of poison splines.

BASIS AND JUSTIFICATION

At the present time, when a Hanford reactor is shut down from normal operating levels, it will undergo a period, lasting from 32-38 hours, during which the poisoning effect of the Xe^{135} forces the reactor to remain subcritical. Inasmuch as many of the causes of these shutdowns are of such a nature that they can be rectified in less than this minimum downtime, a means of overriding the xenon poisoning effect and thus permitting earlier startup or even startup at any time could have very large economic incentive.

A preliminary study has been made to determine the enrichment requirements necessary to bring a reactor to critical before a minimum downtime has elapsed. The result was that the enrichment requirements and associated operating requirements would be relatively small if the enrichment were placed in a block of process tubes in the central portion of the reactor. The excess reactivity provided by the enrichment would be negated by the usage of splines in this region during normal operating conditions (see Figures 1 and 2). The poisoning effect per spline is equivalent to the reactivity contribution (related to natural uranium) of 2.4 enriched columns; each central enriched column will be supplied with a spline cap.

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The bringing of a reactor to critical with such a loading, while reducing minimum downtime, would increase the nonequilibrium operating losses to some extent during the rise to equilibrium levels because of the initial central flux peak and would thus reduce in

part the potential gains of the core loading. Also the actual length of time from startup to normal turnaround levels would be lengthened because of the very nature of the type of loading being attempted. However, experience with this method should permit more rapid rates of rise from turnaround to equilibrium levels because of the greater inventory of xenon present, and with the development of optimum control techniques the nonequilibrium loss increase may be relatively small. Figure 3 sketches the rate of power level increase in terms of allowable flux configurations during power level increases.

LOCATION AND SHAPE OF THE CORE CHARGE

The core ideally should be placed in the region of maximum "startup" neutron flux. This position would be in the near center portion of the reactor where for an "all-rods-out startup" the maximum flux levels would be found. The limiting factor in such a choice is the total control problem. The core location is shown in Figure 4. The mixed charge length of 29 pieces of standard 0.96 enriched slugs, flanked on either end by natural slugs, as is shown in Figure 5, is specified rather than the normal 34-piece enriched charge length in current use in order to center the enriched portion of the charge within the vertical safety system's volume of control. While such a limitation on the charge length of the enrichment is not necessarily a prerequisite for the satisfaction of the total control criteria to be applied, it is felt that a completely conservative approach to the first core loading is warranted in view of the difficult geometrical problems which would be induced when evaluating the total control criteria for a longer enriched charge length. The natural slugs are added to either end of the enriched charge so as to minimize the operational front-to-rear flux peaking caused by short charge lengths. It is anticipated that during normal operation the longitudinal flux peak in this region should not be significantly different from present conditions.

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This production test authorizes an initial test loading of 49 standard 0.96 per cent enriched columns centered within D Reactor. Each enriched column is to be supplied with a spline cap and associated upstream dummy charge. Such a loading should result in a

minimum downtime which would be nine to twelve hours shorter than exists at present. Safety studies indicate that there will be no total control nor speed of control limitations brought about by this loading provided that the normal total control and speed of control criteria are satisfied as indicated in the appendix on Nuclear Safety Analysis.

OPERATIONAL PROCEDURES AND REQUIREMENTS

I. Core Loading

A. Column Pattern

In the charging of the enrichment core for this test, the following 49 tubes will be charged with 0.96 per cent enriched fuel elements and equipped with spline caps:

				2872				
		2770	2771	2772	2773	2774		
	2669	2670	2671	2672	2673	2674	2675	
	2569	2570	2571	2572	2573	2574	2575	
2468	2469	2470	2471	2472	2473	2474	2475	2476
	2369	2370	2371	2372	2373	2374	2375	
	2269	2270	2271	2272	2273	2274	2275	
		2170	2171	2172	2173	2174		
				2072				

B. Charge Pattern (See Figure 3)

The loading charge shall be as follows: 16-8" dummies + 6 regular I&E slugs + 4-0.96 per cent enriched slugs + 1 mixer slug + 24-0.96 per cent enriched slugs + 4 regular I&E slugs + 14 dummies for the spline cap seating charge.

C. Core Loading Sequence

The loading of the charges shall proceed in the following manner:

1. All the tubes will be charged during one period of time, not interrupted by other front face work unless it becomes essential to do so.
2. The Ball 3X system shall be unbypassed.
3. After each E-column has been charged, any spline prescribed for that column shall be inserted before charging is started on the next tube.

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D. Spline Pattern

A total of 22 splines shall be charged for local reactivity matching requirements. At least three splines must be located within any square block of nine tubes within the enriched area. The following pattern is suggested:

2669	2770	2671	2772	2673	2774	2675
	2570				2574	
2469		2471		2473		2475
	2370				2374	
2269		2271		2273		2275
	2170		2272		2274	

The splines which are to be used in the above tubes for normal control purposes shall be inserted to a depth of 30 feet from the front cap; which distance corresponds to the downstream end of the enriched charge.

In the event that a spline cannot be inserted in an indicated tube, any adjacent unsplined core tube may be used; however, the final result of the splining shall be such that except during the special startups permitted by this production test, no more than two lattice units shall separate a splined tube from its nearest neighbor and that no square of tubes within the enriched area shall contain fewer than three standard length splines. In all cases the actual splining operation shall be governed by Process Standard C-120.

II. Startup Procedures for a Cold Startup

A. Pre-startup Control Requirements

1. If the expected outage time will exceed the normal "minimum downtime," all of the prescribed "total control" splines shall be inserted into the core and shall not be removed for startup reactivity purposes. These conditions being met, normal pre-startup and startup requirements and procedures shall be followed.

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2. If an attempt will be made to reduce minimum downtime by the method permitted in this production test:
 - a. The 3X system shall be unbypassed.
 - b. The zone temperature monitoring system shall be in service.
 - c. At least one-fourth of the "core" tube thermocouples shall be monitored on the "cornpopper," the monitored tube thermocouples being symmetrically representative of the core.
 - d. Both subcritical monitors shall be functioning properly.
 - e. Beckman settings
 - f. A Pile Physics representative shall be present before horizontal rod pulls are initiated and during operation at least until those splines required for "normal control" of the enriched zone have been re-charged.

B. The Approach to Criticality; Startup Rod and Spline Withdrawal Sequence

1. Pull the VSR's as prescribed in Process Standards.
2. Position No. 2 and No. 8 HCR's to 135 inches, all others being full in.
3. Pull No. 5 HCR to 180 inches.
4. Follow the normal HCR withdrawal sequence as specified in the 105 D Process Physics Data Manual for all HCR's except No. 5 HCR.
5. After all rods except No. 5 HCR have been removed, pull the first spline, using the spline coiler system, from tube 2471.
 - a. All spline removals shall be performed by means of the controls in the control room.
6. Wait at least three minutes, then repeat step 5, for another spline, removing the splines radially outward from the center of the enriched core.
7. During the approach to critical, a reciprocal count rate measurement shall be maintained by the Pile Physicist present after each spline pull so that

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the approach to critical can be monitored.

8. If a rising period is observed before the completion of a spline withdrawal, the spline removal shall be terminated; further control will be accomplished with No. 5 rod. If no rising period is observed after completion of the spline withdrawal, No. 5 HCR shall be pulled to 250 inches, in steps of ten inches per minute, whereupon a minimum outage shall be awaited.
9. For each cold startup the physicist will supply a curve valid until the reactor is started up which will limit the number of splines which can be out of the reactor as a function of time. This curve will be necessary to assure that total control requirements are maintained during spline withdrawal to critical. Actually, unless an error were made in the reactivity calculations the reactor will become critical during the spline pulls before this total control limit on the number of splines is reached. In the unlikely event the reactor were not critical when this limit was reached it will be necessary to insert splines as required by the curve thus preventing startup. Once the tube temperature rise in the central core has exceeded five degrees the limits presented by this curve would not be applicable. After this time it is sufficient to assume that during operation the total control restrictions would be satisfied by inserting and removing poison to achieve or maintain a balanced flux distribution.

C. Post-Criticality Procedures

1. Upon observing a first indication, a rising period no shorter than 30 seconds shall be maintained. The initial control of the rising period shall be maintained by the insertion of No. 5 HCR, supplemented by No.'s 4 and 6 HCR's as necessary.
2. The power rate-of-rise for any "core" tube shall not exceed 3 C/min and the total power level shall not exceed 50 MW/min; adherence to both limits is to be monitored during the power rise.

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3. If the enriched core is being utilized, the limit to be used with regards to initial power levels shall be a core tube limit of 1000 KW. As soon after startup as the pile is under stable control as determined by Processing supervision and the Pile Physicist, normal tube power limits and temperatures, as defined in the Process Standards and any special speed of control restrictions may be observed in this region.
4. Upon reaching the core tube power limit, compensation for reactivity gains shall be accomplished by the insertion of splines into the central core and the usage of No's. 4, 5 and 6 HCR's for fine core control during the splining operation. The spline insertion rate shall be such that no more than one of the HCR's (4, 5 and 6) shall be allowed to penetrate the reactor more deeply than 100 inches. In the unlikely event that such control of the HCR's cannot be maintained while the reactor core is in use, the reactor shall be scrambled by the No. 1 safety circuit and total control poison requirements as determined by the physicist shall be inserted. Failure to insert enough splines could require a partial core discharge as determined from total control requirements. Normal spline insertion rates should very adequately compensate the reactivity gain rate in the central core after startup.

III. Startup Procedures for a Secondary Cold Startup

If a reactor shutdown occurs during that phase of the startup in which the enriched core is being used, and providing that the normal conditions for a secondary cold startup are met, the following procedures shall be observed.

- A. If the enriched core is not to be used for the secondary cold startup, all of the prescribed "normal control" splines shall be inserted into the core and shall not be removed for startup reactivity purposes. This condition being met, normal secondary cold pre-startup and startup requirements and procedures shall be followed.

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- B. If the enriched core is to be used the following procedures shall be observed:
1. Sufficient core splines shall be inserted to insure that the reactor will be subcritical with the VSR's out and all HCR's out with the exception of No. 5 HCR which will be positioned at 180 inches.
 2. The above condition being met, the procedures set forth in this document under the heading "Startup Procedures for a Cold Startup" shall be followed.
 3. In determining the reactivity worth of HCR's, No's. 4, 5 and 6 for removing rod during a secondary cold startup when the core is utilized, the following values are to be used for that part of the HCR system which lies in the core (i.e., within the region from 180 inches to 110 inches).

HCR No. 4:

HCR No. 5:

HCR No. 6:

For those HCR's which lie outside of the core, the normal evaluation as set forth in the D Process Physics Manual will be used.

The purpose of this secondary cold startup procedure is to permit leaving a portion of the full complement of normal total control splines out when a lesser number very definitely satisfies safety requirements and sufficient scram recovery time is available to make a well controlled deliberate startup.

IV. Miscellaneous Operating Restrictions

- A. During operation at equilibrium conditions less than the number of splines specified to meet total control requirements may be in the reactor. Following a shutdown from which a hot startup is not successful all total control splines shall be inserted within the first eight hours after the shutdown.
- B. Following a scram from equilibrium or near equilibrium conditions a hot startup may be attempted so long as no splines in the enriched core are removed after the shutdown is initiated.

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- C. It is permissible to insert splines into the core at any time; however, splines are not to be withdrawn from the core until the reactor has operated at 50 per cent or more of equilibrium level for a minimum of one hour following a cold or secondary cold startup. Following a hot startup splines may be withdrawn as necessary to maintain efficient control or even to continue operating after the reactor reaches 50 per cent or more of its pre-shutdown level.
- D. Splines are not to be counted for total control purposes if they have been in the reactor more than 50 operating days.

TERMINATION

This test will be terminated with the discharge of the first enriched core load as specified herein. The material shall be discharged during one outage at normal exposure for enriched material. When discharged, total control splines will be removed from the row to be discharged, subsequently that row shall be discharged before splines may be withdrawn from the next row.

COSTS

The approximate incremental cost of using the 49 tubes of enrichment for one metal cycle will be _____.

A minimum spline cost will be about _____ (at \$15 per spline). Additional spline costs will result from utilizing the block to achieve an earlier startup. Although there is no detailed schedule assuring that this enriched core will be utilized for achieving earlier startups, it is estimated, based on past operating experience, that about four startups will be shortened in this manner during the two-three months that the core is in the reactor. It is estimated that the gain from one outage shortened by the full amount possible will nearly pay for one cycle of the core. Any additional outage time saved would be pure profit except for the relatively small cost of additional splines.

REACTOR

This initial test will be performed at D Reactor.

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RESPONSIBILITY

D Processing Operation - Responsible for operating continuity, safety, and for charging and discharging the enriched core in accordance with safety restrictions specified in this report.

Pile Physics Unit - Responsible for providing complete instructions for satisfying total control requirements and for monitoring compliance with these requirements, for providing detailed operating technique recommendations designed to maximize operating efficiency, and for analyzing the results, developing and securing approval for modified techniques as indicated from initial experience, and issuing a final report with appropriate recommendations.

Pile Physics Unit
Operational Physics Sub-Section
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

JF Jacklevick:gs

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APPENDIX

NUCLEAR SAFETY ANALYSIS

INTRODUCTION

The two cases of possible concern in terms of nuclear safety are:

- A. A rapid reactivity gain in the wet reactor during that time in which the enriched core is active.
- B. The total control aspects associated with a reactivity gain caused either by xenon decay in the wet reactor or the instantaneous loss of process water.

The purpose of this appendix will be to demonstrate that the nuclear safety requirements in both cases are satisfied fully, as well with the enriched block as normal loadings are satisfied with current procedures and safety requirements.

DISCUSSION

A. Wet Reactor

The possibility of a rapid reactivity gain in the wet reactor while using the core can occur during the approach to critical and during that period in which the core is being used to bring the reactor to normal power levels. In the first instance, prior to pulling "core" splines, the HCR's and other poisons will have normal reactivity strengths; as the "core" splines are withdrawn reactivity strengths of materials in the core region will increase by many factors.

While pulling splines from the enriched core during the approach to criticality, there is the possibility that the reactor, being just subcritical at the beginning of a spline pull, would be driven supercritical with a period equal to the reactivity worth of a full spline. If such a situation were to occur, no potential hazard would exist because of the following reasons:

First, the "core" spline which upon complete removal would cause the maximum reactivity gain would be the central "core" spline when pulled out last, all other core splines

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already having been removed. The maximum reactivity gain to be realized under these conditions would be such that a period of no less than 30 seconds (162 c-mk) would be observed.

Second, the spline removal process, which takes approximately 90 seconds for completion, can be stopped automatically from the control room at any time during the removal, thereby giving instantaneous poison removal control.

Third, inasmuch as the spline removal process will be initiated with the splines in the center of the core and progress radially outward, the above mentioned "maximum reactivity" case should not be realized inasmuch as the last spline pulled will be in a position of lower flux than for the calculated case. During the entire "approach to criticality" a reciprocal count rate graph will be plotted so that the likelihood of an unobserved premature criticality condition such as postulated above will have little chance of occurring.

Figures 6, 7 and 8 show the average, maximum and instantaneous rates of reactivity gain associated with various spline and enrichment concentrations.

During that period in which the core is being used to bring the reactor to normal equilibrium levels splines will be inserted, no splines being pulled throughout this phase of the operation. HCR's will be pulled to compensate for any net reactivity loss caused by the spline insertion. This leads to the possibility that an HCR might be withdrawn too rapidly, thereby causing a reactivity gain. Ignoring the fact that a spline will be in the process of being inserted at this time, thereby lessening the effect of an HCR withdrawal, it can be seen from Figure 10 that even under the worst conditions, that is, with the core operating and no splines inserted, a maximum rate of gain of 0.28 mk/sec is possible during the rod removal. If the rod were in its position of maximum reactivity worth and then were to be pulled for 7 sec. or 55 inches a possible period of 30 sec. could be obtained. This, of course, is

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assuming that the core is loaded to the point where a complete xenon override is possible, that no splines are in the core, and that the reactor is just critical at the instant of rod removal. Also prescribed nuclear flux monitor trip settings as specified in the procedural portion of the report will ensure that a safety trip would occur before the reactor could be damaged. Except for the fact that under normal operation the minimum sensitivity of the instruments guarantees the trip setting will be satisfied, while with the block the maximum trip setting will be too high and procedures must guarantee that the trip is not too high, this nuclear safety aspect is fully as well satisfied as with the normal load. In fact, since the location of the maximum powers is in a small and well-known area possible local flux increases are less likely with the central core than with a normal load.

B. Dry Reactor

The total control aspects associated with a reactivity gain caused by the instantaneous loss of process water can be resolved in the following manner.

If a symmetrical reactor loading of cylindrical configuration has a $k_{eff} = 1$ and is then driven subcritical ($k_{eff} < 1$) by a safety system whose geometry is such that it passes through the center of the reactor loading, then the degree to which the reactor is driven subcritical will be dependent upon the ratio of the integrated flux squared weighting of the critical reactor within the control region to that of the critical reactor outside of the control region.^{/1/}

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Now, the reactivity gain or increase in material buckling of a reactor upon complete loss of water is insignificantly greater for standard enriched metal than for natural (unenriched) metal.^{/2/} Therefore, if "wet" reactors whose loadings vary in enrichment concentration and location but have identical k_{eff} 's experience a complete loss of water, the relative amounts by which these reactors will be driven subcritical upon insertion of the safety control system will be dependent upon the ratio of the

/1/ HW-60439, "Operational Reactivity Accounting by One-Group Theory," GR Parkos, 6-18-59
/2/ HW-68250, "TC Aspects of Fringe Poison Loading," AD Vaughan, 1-26-61

integrated flux squared weightings of the controlled and uncontrolled regions of the critical reactors.

The application of the above statements to the total control problem in the xenon override case is as follows:

Assume two water cooled reactors, A and B, A being a normal Hanford type reactor and B being a similar reactor differing only in that it has an enriched core. Second, assume that both reactors are being held just critical, the core in B reactor being necessary to bring it to this point because of the excess xenon present. In this case $k(A)_1 = k(B)_1$ [See Figure 11-A]. Now let each of the reactors lose its coolant, then $k(A)_2 = k(B)_2$ [See Figure 11-A]. Since the strength of a poisoning system is proportional to the integrated flux squared weighting of the region through which the poison passes, and since the core of reactor B is approximately centered within the vertical safety system, the integrated flux squared weighting of the safety system in the region through which the safety system must pass will be greater in B reactor than in A reactor, or in terms of k_{eff} , $k(A)_3 > k(B)_3$. Thus if $1 > k(A)_3$, then $1 > k(B)_3$ [See Figure 11-C]

Notation

$k(A)_1$ = k_{eff} of reactor A, case 1

$k(B)_1$ = k_{eff} of reactor B, case 1

$k(\)_m$ = lattice multiplication factor for fuel

$\S k_L$ = reduction in k due to xenon present

$\S k_P$ = reduction in k due to supplementary poison

$\S k_D$ = increase in k due to water loss

$\S k_C$ = [?]increase in k due to insertion of the vertical safety system

$\S k_G$ = change in k due to graphite heating

Therefore, in Case I, the wet case with no safety system inserted the following applies:

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$$k(A)_1 = k(A)_m + \sum k(A)_L + \sum k(A)_P = 1$$

$$k(B)_1 = k(B)_m + \sum k(B)_L + \sum k(B)_P = 1$$

$$k(A)_m < k(B)_m \Rightarrow |\sum k(A)_L| < |\sum k(B)_L|$$

$$\text{such that } k(A)_1 = k(B)_1$$

This means that since reactor B has an enriched core, then for it to be just critical it must have more xenon present than reactor A which is also just critical. The flux squared shapes of these reactors is shown in Figure 11-A.

In case II, the dry case with no safety system inserted, the following applies:

$$k(A)_2 = k(A)_m + \sum k(A)_L + \sum k(A)_P + \sum k_D(A)$$

$$k(B)_2 = k(A)_m + \sum k(A)_L + \sum k(A)_P + \sum k_D(B)$$

$$\sum k_D(A) = \sum k_D(B) \Rightarrow k(A)_2 = k(B)_2$$

Again, this means that since the reactivity gain ($\sum k_D$) of a reactor upon complete loss of water is insignificantly greater for enriched loadings than for unenriched loadings then $\sum k_D(A) = \sum k_D(B)$ and so the relative reactivities of reactors A and B see no significant change. Hence $k(A)_2 = k(B)_2$. The flux squared shapes of these reactors are also shown in Figure 11-A, these curves having been normalized to unity and so being the same for both case A and case B.

In case III, the dry case with the safety system inserted, the following applies:

$$k(A)_3 = k(A)_m + \sum k(A)_L + \sum k(A)_P + \sum k_D + \sum k(A)_C$$

$$k(B)_3 = k(B)_m + \sum k(B)_L + \sum k(B)_P + \sum k_D + \sum k(B)_C$$

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Now, because of the flux-squared shapes of reactors A and B, it can be seen that when the control system is weighted over the integral of these curves, that

$$|\sum k(B)_C| > |\sum k(A)_C| \quad \text{which implies that}$$

$k(A)_3 > k(B)_3$. The flux-squared shapes of these reactors with safety system inserted is shown in Figure 11-B.

Thusly it is submitted that, at the instant of water loss, the critical "cored" reactor or (B) will be driven more subcritical than the uncored reactor (A) upon insertion of the safety system. Figure 12 shows the relative reactivity requirements necessary to bring dry, "cored" reactors of various core enrichment densities and sizes to critical after the Ball 3X safety system has been inserted.

It finally remains to be shown that the uncored reactor described above has a greater k_{eff} than that of the cored reactor at the moment of meltdown after a water loss.

Inasmuch as reactor B, the cored reactor, will have an earlier minimum time than the uncored reactor A, (see Figure 2) then if a water loss occurs at this point, the period from water loss to tube meltdown will see a greater rate of xenon decay for Reactor B than for Reactor A which in turn means that Reactor B will see a more rapid rate of reactivity gain than will Reactor A. On the other hand, since the time from shutdown to minimum time, the time at which a water loss is postulated, will be shorter for Reactor B, so too, will be the time from water loss to meltdown^{3/}, thereby shortening the length of the period during which B Reactor will be gaining reactivity due to xenon decay as compared to A Reactor. The result of these two actions is that the net gain in reactivity due to xenon decay can in some cases be greater for B Reactor than for A Reactor. However, this gain will be nearly homogeneous over the reactor and so can be treated in the same terms as were the reactivity gains and losses at the time of water loss. Therefore, looking again at case III and shifting the area of inspection from water loss time to meltdown time, we find that:

At the instant of water loss (from case III)

$$1) \quad k(A)_3 = k(A)_m + \sum k(A)_L + \sum k(A)_P + \sum k_D + \sum k(A)_C$$

$$1(B)_3 = k(B)_m + \sum k(B)_L + \sum k(B)_P + \sum k_D + \sum k(B)_C$$

$$|\sum k(B)_C| > |\sum k(A)_C| \Rightarrow k(A)_3 > k(B)_3$$

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2) At the instant of meltdown:

$$k(A)_4 = k(A)_3 + \sum k_2(A)_L + \sum k_G$$

$$k(B)_4 = k(B)_3 + \sum k_2(B)_L + \sum k_G$$

Therefore, for $k(A)_4 > k(B)_4$, so as to preserve the method of attack in satisfying the total control criteria, the following must be true:

$$|\sum k(B)_C| - |\sum k(A)_C| > |\sum k_2(B)_L| - \sum k_2(A)_L$$

which in words means that the relative gain in reactivity due to xenon decay must be less than the amount by which the safety system lowers the k_{eff} of B Reactor below that of A Reactor. Fortunately this is indeed the case as can be seen from Figure 13.

It can now be concluded that, the preceding derivations being true, the total control criteria at the instant of water loss or meltdown after a water loss in the "core" case will be satisfied if the criteria have been satisfied for the uncored reactor with the same k_{eff} at the moment of water loss or meltdown. This implies that the currently accepted "square pile" total control concepts may be applied to the uncored reactor at its "minimum time" reactivity conditions thereby satisfying the total control for any "core" reactor which has a short or minimum time.

In each of the preceding determinations of both "xenon override" potential and "total control" comparison relationships, a one-group diffusion theory approximation in cylindrical geometry was used. Operational Reactivity Accounting by One-Group Theory by G. R. Parkos, HW-60439, was used as a reference in obtaining the dimensional and lattice multiplication parameters.

The actual calculational determination of the various values used was performed on the 7090 through the use of "Zilch," a one-dimension one-group diffusion theory flux matching program by G. F. Bailey.

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FIGURE 1
Hours from Normal Minimum Time

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The shutdown xenon reactivity transient vs. time with
"core" enrichment strengths necessary for various re-
duced minimum times.

R = MK

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Figure 3
Rate of Rise to Equilibrium in Terms of Allowable Flux Shapes When Utilizing an Enriched Core

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Reference, Pg. 23, HWN 2885
Personal Notes, J.F. Jaklevick, Jr.

Radius in cm

Figure 4

Location of initial "xenon-override" test loading at D Reactor. Spline caps shall be inserted on each of the indicated tubes.

Figure 5

Charges and Relative Displacement

Standard Loading I&E Slugs (31 + 1 Mixer)

16 Dummies	9 - I&E	M	22 I&E	Upstream Seating Charge
128 inches	79.8 inches	8.9 inches	145 inches	113 inches
	7.0		195.0	
			283.7	233.7

Core Loading, I&E + I&E² Slugs

16 Dummies	6 I&E	4 I&E ²	M	24 I&E ²	4 I&E	Upstream Seating Charge
128 inches	53.2 inches	26.6 inches	8.9 inches	159.4 inches	35.5 inches	113.6 inches

Average maximum spline penetration

← 384 inches →

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I&E = 8.865 inch (ave) natural uranium slug

I&E² = 6.64 inch (ave) 0.96% enriched slug

M = 8.865 inch (ave) water mixer slug

Dummy = 8 inch filler slug

Figure 6

HW-71809-RD

Total number of splines needed to compensate for a given number of 0.96% enriched columns. To satisfy total control requirements during an outage, the number of splines needed during reactor operation at equilibrium levels can be found by multiplying the indicated number by the factor 0.88.

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Figure 7

Worth of one spline in the center of an enriched
core of constant radius versus number of homo-
geneously distributed E-columns in that core.

Core Size = 120 cm

HWN = (1000) - KD

K = reactivity in C-mk units

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Reference: Pg 18, HWN 2885
Personal Notes, J.F. Jaklevick, Jr.

Figure 8

Figure 9

HW-71809-ED

-2b-
R = C-mk

Rod Worth Vs. Position in Reactor

This curve is calculated for the maximum loading which would be used at a 9-rod reactor.

Far Side

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Near Side

Reference: Pg 17, HWN 2885
Personal Notes: J.F. Jaklevick, Jr.

Cm from centerline

Cm from centerline

300

200

100

600 500 400 300 200 100 0 100 200 300 400 500 600

Figure 10

HW-1809-KU

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Rate of change in reactivity per second versus position of rod tip as a central HCR is moved in the core loaded reactivity. This curve is calculated for the maximum loading which would be used at a 9-rod reactor.

Figure 11-A

Case I $k(A)_1 = k(B)_1 = 1, k(A)_m < k(B)_m \Rightarrow |\int k(A)_L| < |\int k(B)_L|$

Case II $k(A)_2 = k(B)_2 > 1, \int k(A)_D = \int k(B)_D = \int k_D$

Figure 11-B

Case III $|\int k(A)_C| < |\int k(B)_C|$

$\therefore k(A)_3 = k(A)_2 + \int k(A)_C; k(B)_3 = k(B)_2 + \int k(B)_C$

$\Rightarrow k(A)_3 > k(B)_3$

Note: The areas under each of these curves have been normalized to unity.

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Figure 13

These curves indicate the amounts by which core loadings of various sizes and densities are subcritical relative to a "no core" reactor at the instant of meltdown after a water loss.

Ball 3X system inserted
 f = core density

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