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RECOMMENDATIONS TO APPLY THE "SQUARE
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RECOMMENDATIONS TO APPLY THE "SQUARE FILE" TOTAL CONTROL CONCEPT

INTRODUCTION

HW-62884 - Hanford Safety System Capacities by "Square File" Approximations, presents the technical basis for a new concept in total control evaluation. The present report is a recommendation for the adoption of the new method, with appropriate instructions for its application.

All curves and recommendations included herein are compatible with the concept established in the reference report; local control strengths assumed are those recommended in the parent document, with the one exception noted below.

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RECOMMENDATIONS

It is summarily recommended that the "square pile" concept be adopted for all disaster total control calculations, and that the basic reactor constants listed in HW-62884, with the exception of the author's recommendation for Ball 3X local strength at the DR Reactor, be used in applying this method. (The local strength assumed for DR channels should be consistent with that of C and H Reactors, which have identical vertical channels.)

Curves are included for each reactor type, indicating allowable enrichment based on appropriate local control strengths. Furthermore, an example of the analytical method is included.

DISCUSSIONA. The "Square Pile" Concept

In the past, safety system capacities in the disaster situation have been calculated by a combination of perturbation theory and one-dimensional, one-group diffusion theory. Analyses then were subject to the weaknesses and inaccuracies of both theories, in particular:

- (1) Perturbation theory will not accommodate large reactivity (and hence flux) changes.
- (2) Application of diffusion theory to a slab is either a one-dimensional or a poor two-dimensional approximation to a three-dimensional system.

The approximations involved necessitate large factors of conservatism in the application of analytical results in satisfying control criteria.

The proposed method is not subject to perturbation theory limitations, and is a better approach to a three-dimensional analysis than "slab" calculations, since in the present case the use of a cylindrical coordinate system employs only two variables; these are height and radius. (The calculations are made for a pile of infinite height and then corrected for finiteness by subtraction of the vertical leakage component.)

The "square pile" concept¹ is based on firm theoretical ground; it is actually equivalent to considering a pile composed of two critical half-masses separated by an infinite multiplying medium. Criticality will be maintained, so long as the separating medium has a neutron multiplication factor (effective) of unity.² Conversely, if the neutron multiplication in the separating space falls below unity, criticality is no longer maintained.

Thus, this concept assumes a central (separating region) with a negative buckling (reactivity) and considers the conditions for criticality in the two outside regions of positive buckling. (See Figure VII.) Necessary calculations employ Bessel functions, and the problem is characterized by one-dimensional simplicity; however, a sound three-dimensional approximation is achieved.

1. HW-62884 - Hanford Safety System Capacities by the "Square Pile" Approximation - G. R. Parkos, 12-4-59.
2. N-2292 - Principles of Nuc. Power - Ch. 22: Control, J. A. Wheeler, 6-28-44.

DISCUSSION (Continued)A. The "Square Pile" Concept (Cont'd)

The method incorporates several factors of conservatism; it seems appropriate to enumerate several of the most important:

(1) Xenon

Peripheral xenon poisoning effects in the disaster case are assumed to be 0-50 per cent of the calculated effects. Thus the material bucklings outside the central (control) zone are over-estimated by an amount of 50-100 per cent of the calculated xenon buckling.

(2) Enrichment

Enrichment limits are specified for the "near or far-side" (see Figure VIII). Consequently, the calculations assume that the entire E-ring is as strong as its strongest "side"; for example, if a particular reactor has N near-side columns, and (N-5) far-side columns, the critical case is based on an enrichment of N columns on both sides.

(3) Central Zone Poison and HCR's

Poisonous materials (lead cadmium, splines, control rods, etc.) located in the central region of the reactor (within the enrichment ring) are assumed to contribute nothing in the disaster case, except that they may be considered as compensation for "spike" enrichment. To illustrate: if a given reactor has X reactivity units of enrichment, and (X+10) units of poisonous material, only X units are considered effective, as exact compensation for the enrichment.

In summary, then, the bucklings used in the calculations are conservative in all three regions of the reactor.

B. Modifications to Use of HW-62884

The methods outlined in the parent document are to be used in disaster control analyses, with the following exceptions:

(1) Xenon Correction

The curves included herein (Figures I-VI) are to be used in determining allowable enrichment. These curves differ from those in HW-62884 in that xenon is included as a control factor, as mentioned above.

(2) Local Control Strength

These curves are based on the following local strength of the Ball 3X system:

K Reactors	130 μ b
B, D, F, Reactors.	135 μ b
*DR, C, H Reactors.	150 μ b

* The above values were used in HW-62884 also with the exception of DR, for which the B-D-F value was used. Actually, DR's individual VSR and ball channel sizes (and therefore buckling effects) are equivalent to those at C and H; DR's correspondence to the B,D,F, reactors is in total number of channels only.

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DISCUSSION (Continued)B. Modifications to Use of HW-62884 (Cont'd)(3) Horizontal Control Rods

It seems perfectly logical to assume some negative buckling contribution from HCR's that are actually in the reactor at the instant of water loss, as was done under the earlier methods of evaluating total control. Therefore, a method of calculating control rod worth is employed that retains a high degree of conservatism, yet realistically assigns some worth to portions of HCR's that lie outside the region of Ball 3X control.

Basically, no contribution is assumed for HCR's, or portions of HCR's, that lie in the region of the reactor past the near-side radial enrichment ring, and a reduced value (considering "shadowing" effects) is used in the peripheral zone. (The disaster case flux distribution with Ball 3X insertion is given in an earlier work by Simpson.³) Then, assuming an individual rod strength proportional to the square of the disaster case flux (a reasonable assumption in this case) that portion of the rod which penetrates to the inner boundary of the near-side enrichment ring is weighted proportional to the shadowed strength of the entire rod. Thus to calculate the disaster case contribution, the strength of an individual rod in c-mk at full penetration is multiplied by the appropriate factors below (provided that it covers the near-side enrichment ring):

<u>Reactor</u>	<u>Correction Factor</u>	<u>No. Compensated "E" Columns per Corrected c-mk</u>
B,D,F,DR	0.11	0.20 0.125
C and H	0.19	0.20 0.125
KE, KW	0.14	0.125 0.20

Half-rods may count as enrichment compensation provided that they cover the entire near-side from zero penetration to the inner boundary of the near-side enrichment. The correction factors listed above apply in this case. (Scrammability of HCR's in the disaster case is not assumed.)

Thus, as an example, Number 5 HCR at F Reactor is worth 300 c-mk effective reactivity; this will compensate for $(300 \text{ c-mk}) \left(0.11 \frac{\text{c-mk disaster strength}}{\text{c-mk normal strength}} \right) \left(0.20 \frac{\text{compensated "E" columns}}{\text{c-mk disaster strength}} \right) = 6.6 \text{ "E" columns}$ in the disaster case.

Additional enrichment is allowed then at rate determined by the corrected rod worth, assuming 8.0 c-mk/(E column) at the BDF, DR, and C and H Reactors, and 5.0 c-mk/(E column) at the K Reactors.

(4) Temperature Coefficient Reactivity Effects

Temperature coefficient reactivity effects are to be calculated by methods outlined in Simpson's disaster control report, HW-56655 PT 2, pp. 25-26.

DISCUSSION (Continued)

B. Modifications to Use of HW-62884 (Cont'd)

For use in the "square pile" analytical method, the only point that must be ascertained is the "most reactive state." The values presented in HW-56655 are conservative, and should be used until such time as additional data indicate a possible revision.

The curves in the present report are based on xenon at this "most reactive state" - that combination of xenon depletion, exposure-dependent coefficients, and melting times giving the most reactive state following water loss. The individual Area Physicist must determine when that particular state occurs for a given outage or startup.

(5) Ball 3X Lockout

Locking bars may be in place providing total control requirements are met. Satisfaction of these requirements necessitates corrections to the values indicated by the curves.

<u>Reactor</u>	<u>Hoppers Allowed Out of Service</u>	<u>Enrichment Columns Allowed</u>
K	35 inner*	Indicated number from Figure V minus 40 near, 40 far.
C,H	All	Indicated number from Figure VI minus 48 near, 48 far.
BDF	All	Indicated number from Figure I or III minus 19 near, 19 far.
DR	All	Indicated number from Figure II or IV minus 24 near, 24 far.

*The six outer channels at the K's must always be operable since there are no VSR's associated with them. In the event that lock-out becomes necessary, approved poison may be charged as recommended by the assigned Area Physicist.

These values apply when a VSR is inserted in each bypassed channel. During startup, the following ball channels, in addition to the total number of requirements already stated in standards, must always be in service unless approved poison has been charged as recommended by the assigned Physicist.

<u>Pile</u>	<u>Ball Hoppers Always Required when VSR's are Withdrawn**</u>
K	16 outer
C and H	14 outer
BDF	6 outer
DR	6 outer

**HW-56655 PT 1, REV, op. cit.

DISCUSSION (Continued)C. Explanation of Charts

Currently, the only reactors whose operating methods are affected by disaster total control requirements are B, D, F, and DR Reactors. The remaining piles have sufficient geometrical coverage to allow operation at present maximum enrichment levels without the addition of compensating poison. Therefore, the curves presented for these reactors include one additional refinement, a xenon correction, not incorporated in the C and H curves. Xenon is considered as discussed by HW-62884, which recommends that one:

- (1) Calculate xenon strength by conventional methods (existing tables). This value will represent the "local strength" over the entire reactor.
- (2) Assign the full local strength to the central zone, and half the local strength to the region outside the control boundaries.
- (3) Calculate critical combinations of region bucklings, where appropriate reductions are made for xenon poisoning.

Curves for B, D, F, DR, and K are based on this general method. A single curve for the C and H Reactors is presented, since total control criteria are adequately satisfied without relying on xenon.

Figures I through VI are based on the fundamental reactivity properties of the defined regions following water loss, with full insertion of the Ball 3X system and zero insertion of the HCR's; allowable enrichment is presented as a function of the effective lattice buckling, B.

Figure VII illustrates the geometrical approximation used in constructing the "square pile." The two end-sections are assumed joined together and the critical case is calculated. The "central" section must always be "subcritical."*

The bucklings (reactivities) of regions (1) and (3) are not subject to appreciable change through normal loading revisions; they do, however, reflect changes in xenon concentration due to normal buildup and decay. On the other hand the enriched region buckling $\sqrt{\text{Region (2)}}$ may be significantly modified by the routine charging or discharging of E columns or by charging or discharging poisonous material in the region. Thus, any necessary temporary poison may be determined from a chart or graph showing the number of E columns allowed (in the enriched ring as defined in HW-62884; see Figure VIII) versus the xenon status of the entire pile. A series of such curves is provided for various basic lattice bucklings at B, D, C, and H, and for the 38-piece charge at the K Reactors. (The curves for C and H assume no xenon in the reactor. If significant loading changes in the future at these reactors require total control restrictions on production, curves may be calculated from the data in HW-62884 which reflect xenon contribution and hence allow higher enrichment levels.)

* Determine as per Figures 4, 5, and 6 of the parent document, HW-62884.

Xenon at Most Reactive State, mk
Allowable Enrichment vs. Xenon at BDF, DR Reactors
32-Piece Loading

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Figure III

Allowable Enrichment for Various "Effective" Bucklings

BDF Piles, 34-Piece Loading, $B_0 = 105 \mu b$

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Figure IV

Allowable Enrichment for Various "Effective" Bucklings

DR Pile, 34-Piece Loading, $B_c = 150$ ub

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Figure V

Figure VI

Allowable Enrichment for Various Xenon Concentrations
and/or Effective Lattice Bucklings for C and H and K Reactors

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Figure VII A

Figure VII B

Top Views of Typical Hanford Pile

Figure VII A: Actual Geometry

Figure VII B: "Square Pile" Approximations

(Regions 1, 2, and 3 are shown on the face map in Figure VIII.)

Figure VIII

F Reactor Enrichment Pattern as of January 1960
Regions (1), (2), and (3) for the "Equivalent Square Pile"
In Figure VII Are Indicated

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DISCUSSION (Continued)

In each case, subcriticality must be assured in the central section. This is determined from Figure 4 in the original report, HW-62884. With an effective lattice buckling of $97 \mu b$ we see that this section is subcritical on minimum outages, since the "critical buckling inside the control region" is increased to about $153 \mu b$ ($135 \mu b$ balls + $18 \mu b$ xenon); this section will be subcritical even if there is no xenon contribution outside the control region.

In the case of extended outages, additional poison must be charged; this will normally be of little bother, since poison is routinely charged during long outages.

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APPENDIX

Sample Calculation

Example: Calculation of Disaster Control Status for F Reactor

The following data are necessary to calculate the status of F Reactor for a minimum outage (data as of 1/1/60):

Effective dry lattice buckling - - - - - 97 ub¹
 Calculated xenon at minimum- - - - - 18 mk²
 Estimated time, water loss to tube melting - - - - - 20 hours³
 Calculated xenon at that time- - - - - 5.0 mk
 Xenon loss over this period- - - - - 13.0 mk
 Average exposure - - - - - 340 MWD/T
 Temperature coefficient reactivity contribution- - - -13 mk
 Number of near/far side E columns- - - - - 25/14

Since the over-all reactivity loss due to pile heating is approximately equal to the gain due to xenon decay over the heating period the instant of water loss may be considered the most reactive state. Hence the value of xenon that should be used for the curve on Figure III is 18 mk. Extrapolating between the curves for 90 and 100, we find that approximately 30 near or far side E columns are allowed at critical.

In the infinite outage case, there is zero xenon, and we find that -5 E columns are allowed per side. Obviously, 25-(-5) or 30 near-side columns and 14-(-5) or 19 far-side columns must be compensated.

-
1. Calculated as per HW-62884, page 40.
 2. Calculated by current xenon tables.
 3. HW-56655 PT 2 REV, Calculation of Supplementary Disaster Control Requirements Hanford Piles - Part II, Data, D. E. Simpson, 6/15/59, (p. 24).

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