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TOTAL CONTROL VS. REACTIVITY PARAMETERS

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TOTAL CONTROL VS. REACTIVITY PARAMETERS

INTRODUCTION

Changes in pile operating parameters, such as fuel exposure, power, and reactivity gain upon water loss affect the potential reactivity of the operating pile and, therefore, the amount of enrichment required to operate under the desired conditions. Similarly a change in ECT (through enrichment location) changes the amount of enrichment needed to maintain a constant reactivity. Many of the factors which influence the operating reactivity have quite different effects upon the reactivity of the dry pile with the ball 3X system inserted; therefore, changes in operating parameters may cause sizeable changes in requirements for supplementary control to maintain sub-criticality in the dry pile.

It is the purpose of this document to summarize these trends in disaster control requirements for the K piles. The trends are presented as graphs of supplementary control requirements against a single varying parameter. All other parameters are held fixed as specified on each graph. The fuel element (central orifice zone) for all examples is the K-2 slug. In general, the slopes of these curves are only slightly dependent upon the specific values assigned the fixed parameters, although the magnitude of the control requirements may be quite dependent on these values. Unless otherwise noted any dependence of the slope upon the fixed parameter values is not important for the purposes of this document. It is emphasized that the graphs are intended to be descriptive of supplementary control trends rather than definitive in terms of actual magnitude.

For piles other than the K's, the general direction of control trends is the same as those presented here, although the actual changes are quite different for some parameters.

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Figure 1 - Hot Reactivity Change vs. Fuel Exposure

At any particular power level, a change in average fuel exposure will change the potential hot pile reactivity because of changes in both the cold pile long term reactivity gain and the reactivity contribution of the graphite coefficient. Both of these effects increase the hot reactivity with increasing fuel exposure.

This curve provides reactivity information on which enrichment needs are based. It, therefore, supplies background information for interpreting later curves rather than a direct indication of control requirements.

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Figure 1

HOT REACTIVITY CHANGE VS. FUEL EXPOSURE

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Figure 2 - Hot Reactivity Change vs. Pile Power

At any average fuel exposure, variations in pile power cause a change in hot pile reactivity because of changes in xenon concentration, metal temperature coefficient contribution, and graphite temperature contribution. The net effect is a reactivity loss with increasing power level.

Like Figure 1, this curve provides background information rather than an indication of total control requirements.

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Figure 2

HOT REACTIVITY CHANGE VS. PILE POWER

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Figure 3 - Fringe Enrichment Requirements

Based upon the observed enrichment used at about 3100 MW and 800 MWD/T goal exposure with I & E fuel elements (K-2), fringe enrichment requirements were estimated as a function of the hot pile reactivity change from this condition with ECT as a parameter. The enrichment loadings are assumed to be $46T^2$, located as follows:

ECT	E location (lattice units from edge of pile)
2350	9-10
2400	8-9
2450	7-8

In all cases it is assumed that equal amounts of enrichment are located on the top, bottom, and far sides with $3\frac{1}{4}$ more E columns on the near side than on each of the others.

This figure provides additional background information illustrating the dependence of fringe enrichment requirements upon reactivity changes and enrichment location.

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Figure 3

FRINGE ENRICHMENT REQUIREMENTS

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Figure 4 - Central Zone Enrichment Requirements

Central zone enrichment requirements were estimated from the same base operating conditions as for Figure 3. The requirement varies with ECT only because of the difference in central zone size.

This background information complements that of Figure 3.

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Figure 4

CENTRAL ZONE ENRICHMENT REQUIREMENTS

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Figure 5 - Infinite Outage Supplementary Control Requirement vs. Fuel Exposure

The curve shows the calculated supplementary control required to maintain sub-criticality in the dry, xenon-free pile with all ball channels filled. (The supplementary control requirement is the calculated super-criticality of the pile with no controls other than the ball 3X, inserted.)

In the fuel exposure range of interest the overall dry temperature coefficient of reactivity is negative; therefore, the limiting supplementary control requirement in the xenon-free condition is for the cold, dry pile. At average exposures above about 600 MWD/T the overall dry temperature coefficient becomes positive and control of the hot dry pile becomes more restrictive.

(As in all of the curves, the slope is of primary significance rather than the absolute values.) The plotted "long-term-gains" uncertainty is approximately the difference between the K-pile long-term-gains curve in use and the experimental 8-3/8 inch lattice, solid slug, long-term-gains curve of HW-46377.

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Figure 5

INFINITE OUTAGE SUPPLEMENTARY CONTROL REQUIREMENT
VS. FUEL EXPOSURE

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Figure 6 - Infinite Outage Supplementary Control Requirement vs. Pile Power

This curve shows the calculated supplementary control requirement for the dry, xenon-free pile as a function of pile power. The requirement increases with increasing power because additional enrichment is added to make up the hot reactivity loss. Some of this must be added in the fringe; therefore, the increase in supplementary control requirement is greater than the hot pile reactivity loss.

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Figure 6

INFINITE OUTAGE SUPPLEMENTARY CONTROL
REQUIREMENT VS. PILE POWER

Supplementary Control Requirement (ih)

Average Exposure: 400
Goal Exposure: 800
ECT: 2450

Pile Power (MW)

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Figure 7 - Infinite Outage Supplementary Control Requirement vs. ECT

This curve shows the calculated supplementary control requirement of the dry, xenon-free pile as a function of ECT.

The primary reason for the large reduction in control requirement with reduced ECT is that less enrichment is required when located farther from the edge of the pile. (See Figure 3.)

Much of the control requirement reduction, perhaps almost all, which accompanies a given ECT reduction could be achieved by moving only the near side enrichment away from the pile edge with a corresponding ECT reduction less than indicated by the curve.

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Figure 7

INFINITE OUTAGE SUPPLEMENTARY CONTROL
REQUIREMENT VS. ECT

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Figure 8 - Infinite Outage Supplementary Control Requirement vs. Reactivity Gain on Water Loss

This curve shows the calculated supplementary control requirement for the dry, xenon-free pile as a function of the cold pile reactivity gain upon loss of cooling water. The material buckling of the dry lattice was assumed to remain constant at the value for the K-2 fuel element. If both the cold wet and cold dry bucklings change, the resulting effect upon control requirements will be somewhat different.

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Figure 8

INFINITE OUTAGE SUPPLEMENTARY CONTROL REQUIREMENT VS. REACTIVITY GAIN ON WATER LOSS

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Figure 9 - Infinite Outage Supplementary Control Requirement vs. Assumed E-Metal Buckling

This curve shows the calculated supplementary control requirement for the dry, xenon-free pile as a function of the assumed material buckling for the fringe enrichment loading. This reflects the importance in the calculations of uncertainties in this value; it does not represent any change in supplementary control requirement which would be caused by use of a different type of enriched material.

In analysis of the K pile control strength experiments it was found that the apparent buckling of the fringe C-metal enrichment was less than that measured in an exponential pile. No similar reduction is assumed for E-metal; the effect such an assumption would have is indicated on the curve.

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Figure 9

INFINITE OUTAGE SUPPLEMENTARY CONTROL REQUIREMENT
VS. ASSUMED E-METAL BUCKLING

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Figure 10 - Supplementary Control Requirement vs. Outage Length

This curve shows the calculated supplementary control requirement for the dry pile as a function of outage length. This requirement varies with time because of the effects of xenon decay and temperature coefficients of reactivity during the interval between loss of water and process tube melting. Curve 1 is the requirement to maintain sub-criticality of the cold pile at the moment of water loss, plotted as a function of outage length prior to the water loss. The estimated uncertainty due to xenon strength calculations is indicated by the dashed curve beneath Curve 1. Curve 2 shows the requirement to maintain sub-criticality in the hot pile at the moment of process tube melting, plotted as a function of outage length prior to the water loss. A rough guess as to the uncertainty in the temperature coefficient contribution (± 100 ih) is indicated by the dashed curves above and below Curve 2.

For any time of water loss the supplementary control requirement during the interval between water loss and process tube melting will be somewhere below the higher of the values shown on Curves 1 and 2.

For these curves operation at 3100 MW, 400 MWD/T (average), and 2450 ECT is assumed. The curves will have the same shape with changes in these parameters. A reduction in exposure will raise Curve 1 in magnitude and lower Curve 2; an increase in power will cause a slight increase in both curves; a reduction in ECT will lower both curves. An increase in the reactivity gain on water loss will raise both curves.

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Figure 10

SUPPLEMENTARY CONTROL REQUIREMENT
VS. OUTAGE LENGTH

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Figure 11 - Thirty-five-Hour Outage Supplementary Control Requirement vs. Fuel Exposure

These curves show the calculated supplementary control requirement for the dry pile after an outage of about 35 hours, plotted as a function of fuel exposure. Curve 1 is the requirement to maintain sub-criticality of the cold, dry pile at the moment of water loss (35 hours after shutdown). Curve 2 shows the requirement to maintain sub-criticality at the moment of process tube melting after a water loss which occurs 35 hours after shutdown.

Curves for this outage length with varying parameters other than exposure are not included since they follow the same slopes (both hot and cold) as the respective infinite outage curves.

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Figure 11

THIRTY FIVE HOUR OUTAGE SUPPLEMENTARY CONTROL
REQUIREMENT VS. FUEL EXPOSURE

Power: 3100
Average Exposure: 400
Goal Exposure 800
Outage Length: 35 hours

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Figure 12 - Minimum Reactivity Time During a Temporary Poison Push Outage -
Supplementary Control Requirement vs. Fuel Exposure

This curve shows the calculated supplementary control requirement for the dry pile at the time of minimum reactivity (maximum xenon) during an outage for the discharge of temporary poison, or a similar outage after a short period of operation; the requirement is plotted as a function of fuel exposure. Curves 1 and 2 show the requirements for the cold, dry pile and hot, dry pile, respectively, for water loss at the minimum reactivity point. At this time the xenon contribution is about the same as for a 35-hour outage following equilibrium operation; therefore, Curve 1 is the same as Curve 1 in Figure 11. Following a short operating period the process tube melting time is long permitting almost complete xenon decay before tube melting; Curve 2 is higher than Curve 2 in Figure 11 because of the resulting difference in xenon strength at the time of tube melting.

It should be noted that the average fuel exposure is assumed to be one-half the goal exposure. If the average is less than this, which is usually the case, Curve 1 would be lowered somewhat and Curve 2 would be lowered considerably (about 200 inhours for an average exposure of 40 per cent of goal).

Possibly overly conservative assumptions are used in reaching the conclusion that the residual slug heating under the conditions of this example is less than after a 35-hour outage following equilibrium operation. This question might profitably be explored further if total control problems are encountered during temporary poison outages or similar outages after brief operating periods.

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Figure 12

MINIMUM REACTIVITY TIME DURING A TEMPORARY
POISON PUSH OUTAGE - SUPPLEMENTARY CONTROL
REQUIREMENT VS. FUEL EXPOSURE

Power:: 3100
ECT: 2450
P-Push Outage Start-up

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Figure 13 - Ball 3X Capacity and Dry Pile Reactivity vs. Fringe Enrichment Loading

The plotted Ball 3X capacity is the calculated reactivity which would exist if the balls were removed from the pile which is at critical with the balls in. The plotted dry reactivity is the calculated reactivity of the dry pile with the appropriate fringe enrichment loading and a material buckling of $85 \mu b$ everywhere except in the fringe enrichment pattern ($85 \mu b$ is the measured material buckling of green, dry solid uranium, and it is in the neighborhood of the effective dry buckling of current I & E loads with spike enrichment). For both curves the enrichment was assumed to be loaded in the seventh and eighth lattice units from the edge of the pile with about 34 more columns on the near side than on each of the other sides.

The dashed curves show the effect of a ten per cent reduction in assumed E-metal buckling.

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Figure 13

BALL 3X CAPACITY AND DRY PILE REACTIVITY VS.
FRINGE ENRICHMENT LOADING

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Figure 14 - Supplementary Control Requirement vs. Near Side Enrichment

Previous curves do not show the strong dependence of the supplementary control requirement upon the near side enrichment alone. This is shown in the accompanying figure. This effect is due to the severe flux reduction in the center of a K pile when the balls are in which causes pile criticality to be determined almost entirely by the enrichment in the more highly enriched of the near and far sides. Thus if the near side contains significantly more E columns than the far side, the pile reactivity will change hardly at all upon removal of all the far side E columns or upon addition of more far side E columns until the near side number is approached. Conversely a change in the number of near side E columns will change the pile reactivity far more than the same change in the operating flux distribution. It is this fact which permits the introduction of relatively large amounts of supplementary disaster control at small cost in operating pile reactivity, by selectively charging poison into the near side enrichment during the time this control is required.

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Figure 14

SUPPLEMENTARY CONTROL REQUIREMENT VS.
NEAR SIDE ENRICHMENT

Power: 3100
Avg. Exp.: 400
Goal Exp.: 800
ECT: 2450
No. of Fringe E
Columns:
Top: 52.5
Bottom: 52.5
Far: 52.5

Supplementary Control Requirement (ih)

Slope $\approx -20 \frac{ih}{E \text{ Col. (near side)}}$

$70 < E_{\text{near}} < 90$

Number of Near Side Fringe E Columns

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Figure 15 - Illustration of Selective Poison Placement

Curve 1 shows the calculated supplementary control requirement as a function of outage length for 300 MWD/T average fuel exposure (600 MWD/T goal), 3100 MW power, and 2450 ECT. Curve 2 shows the amount of HCR (effective disaster case strength) which would be required to maintain criticality in the wet pile. Curve 3 shows the amount of supplementary control supplied by effectively canceling near side enrichment in increments of 2.7 E columns (~ 2 splines) as required, still maintaining criticality in the wet pile.

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Figure 15

ILLUSTRATION OF SELECTIVE POISON PLACEMENT

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