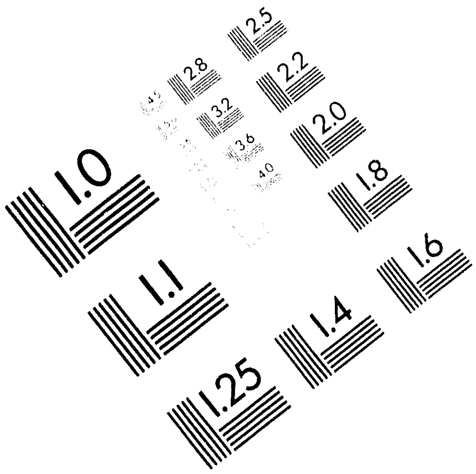

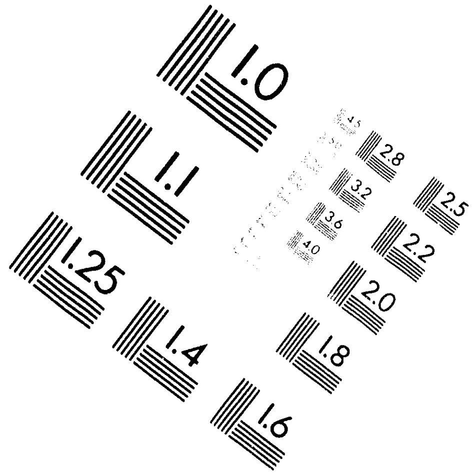

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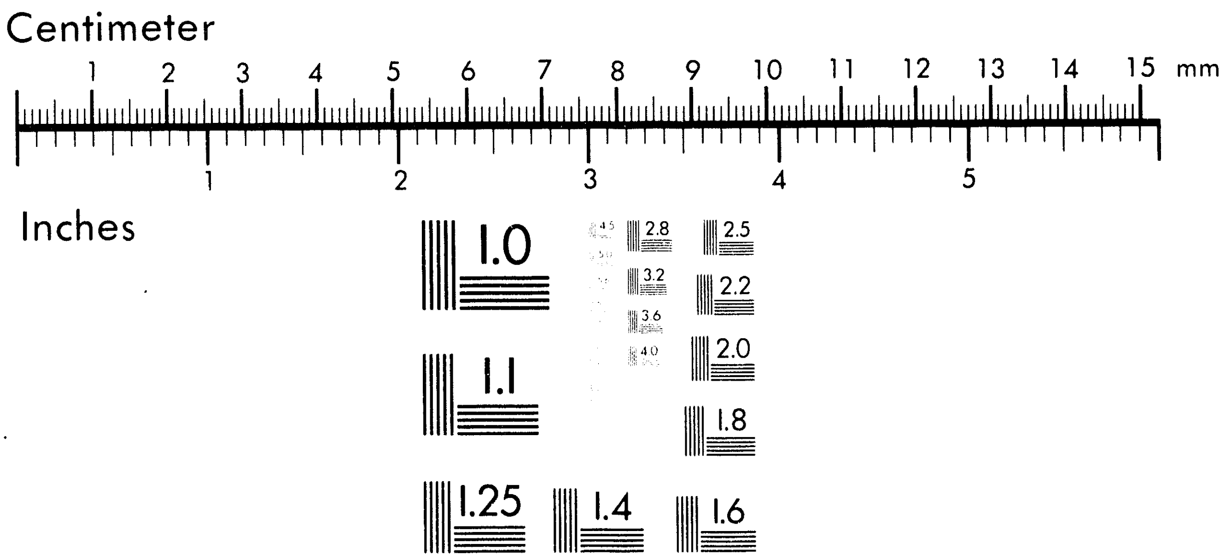

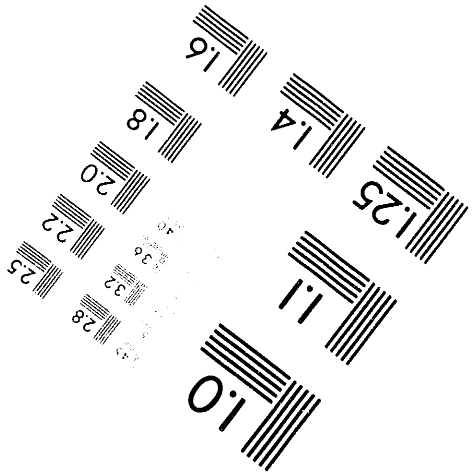

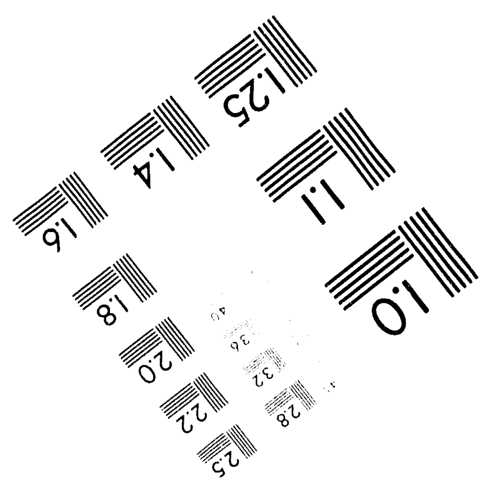

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TITLE
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SIGNIFICANCE OF OPERATING EXPERIENCE WITH POISON SPLINES AT KE REACTOR

INTRODUCTION

The demonstrated operating efficiency performance which has resulted from poison spline usage forces an economic decision concerning the self-supported and bumper fuel element programs. As originally conceived the projection fuel elements would preclude the insertion of a spline under the fuel charge; thus it is very important that means be devised either to make poison spline usage compatible with future pile loadings or to demonstrate that some other supplementary control system, which is compatible with future pile loadings, can approximate the effect that splines have on operating efficiency. This report shows the appreciable performance improvement which has been achieved at KE Reactor through the application of the poison spline system.

SUMMARY AND CONCLUSIONS

Flux distribution control has been significantly improved with splines in spite of operating changes which would tend to increase control problems. The production gains achieved are reflected in improved level operated efficiency and flattening efficiency. Figures 1-4 show the data from which the following results are summarized.

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SUMMARY AND CONCLUSIONS (Continued)

The average level operating efficiency normalized to 2.5 outages per month has increased eight per cent over the pre-spline performance.

Equilibrium flattening data has shown an increase of 2.5 per cent with partial spline usage and four per cent with full spline usage. As with level operated efficiency, the current higher tube powers would have resulted in a decrease in flattening efficiency rather than the increase achieved with poison splines.

These two improvements, level operating efficiency and flattening efficiency, are multiplying effects so that the production gain is indicated by the ratio of the product of these two efficiency improvements, with and without splines. The indicated gains are reduced by twenty per cent to allow for any time operated efficiency loss. For the first five months of 1960 the ratio shows a ten per cent improvement which can be attributed directly to efficient utilization of splines. Further experience with splines should increase production at present power levels to about eleven per cent in excess of production without supplementary control.

Operation under bulk effluent temperature limits would reduce the benefits of radial flattening. Level operated efficiency gains would still be as significant because startup efficiency would remain dependent on the available supplementary control.

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NON-EQUILIBRIUM LOSS PERFORMANCE

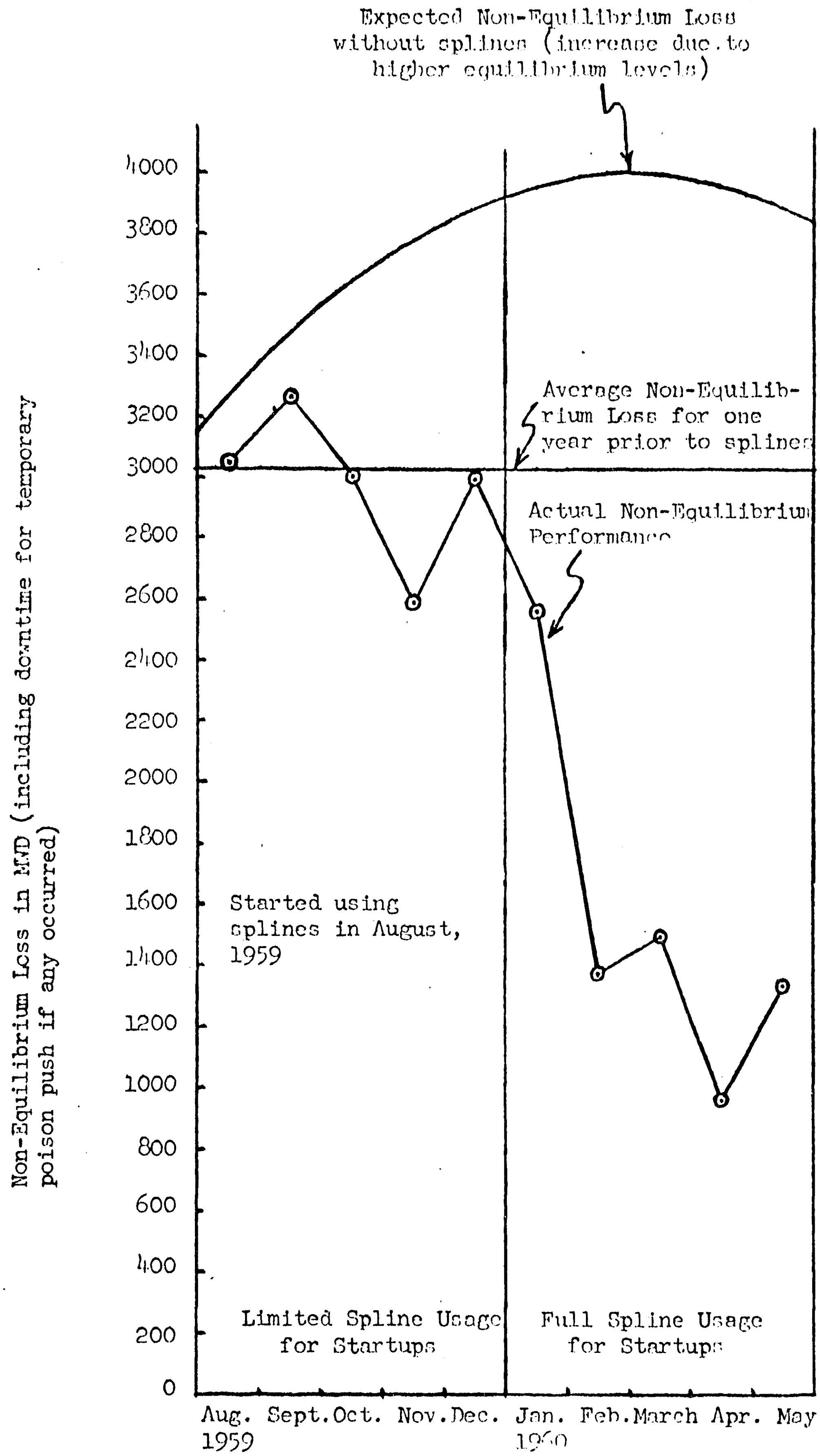

Figure 1

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LEVEL OPERATED EFFICIENCY PERFORMANCE

X(N) - Actual LOE (actual number of outages)

⊙ - Actual LOE normalized to 2.5 outages per month

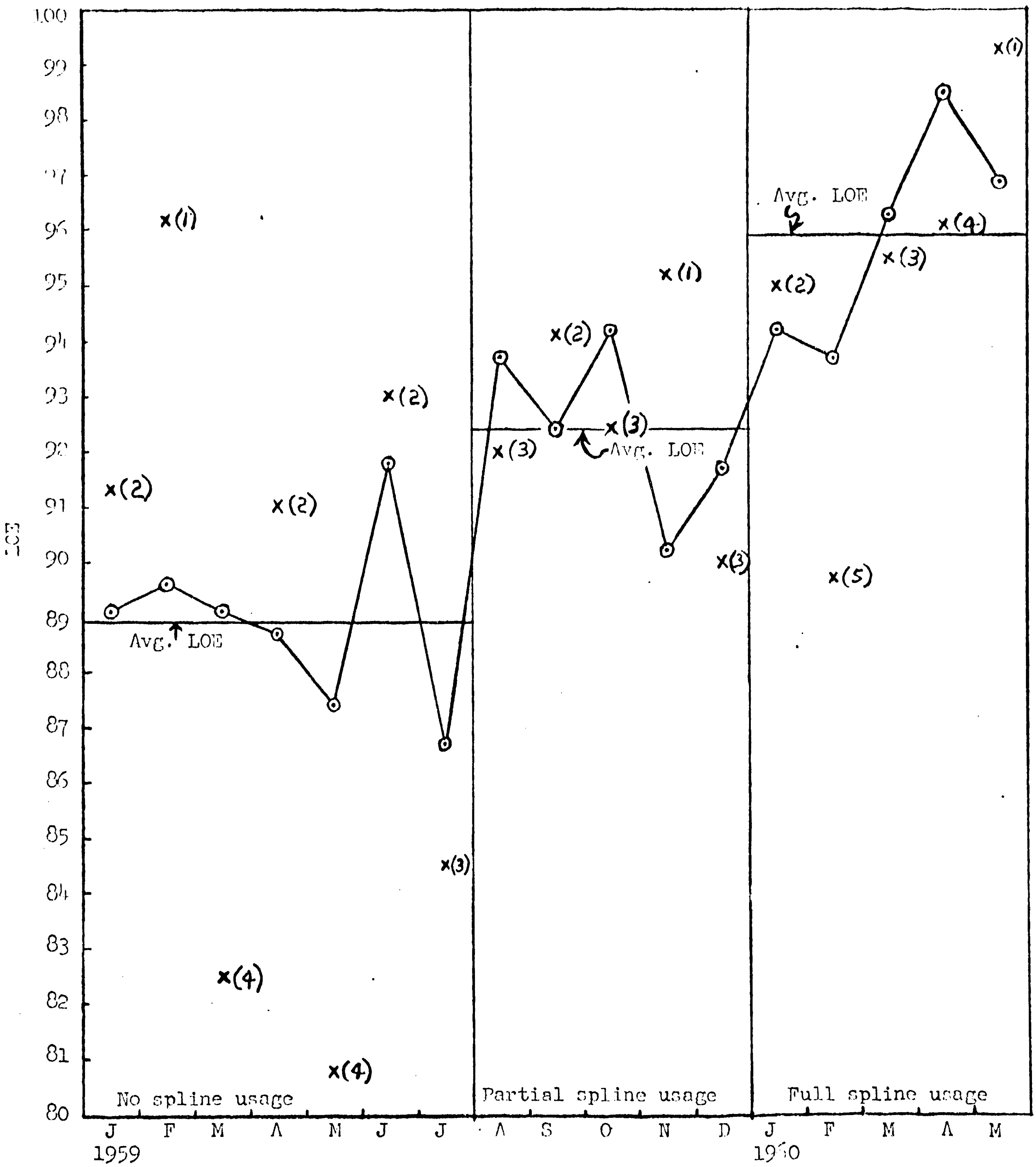

Figure 2

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FLATTENING EFFICIENCY PERFORMANCE

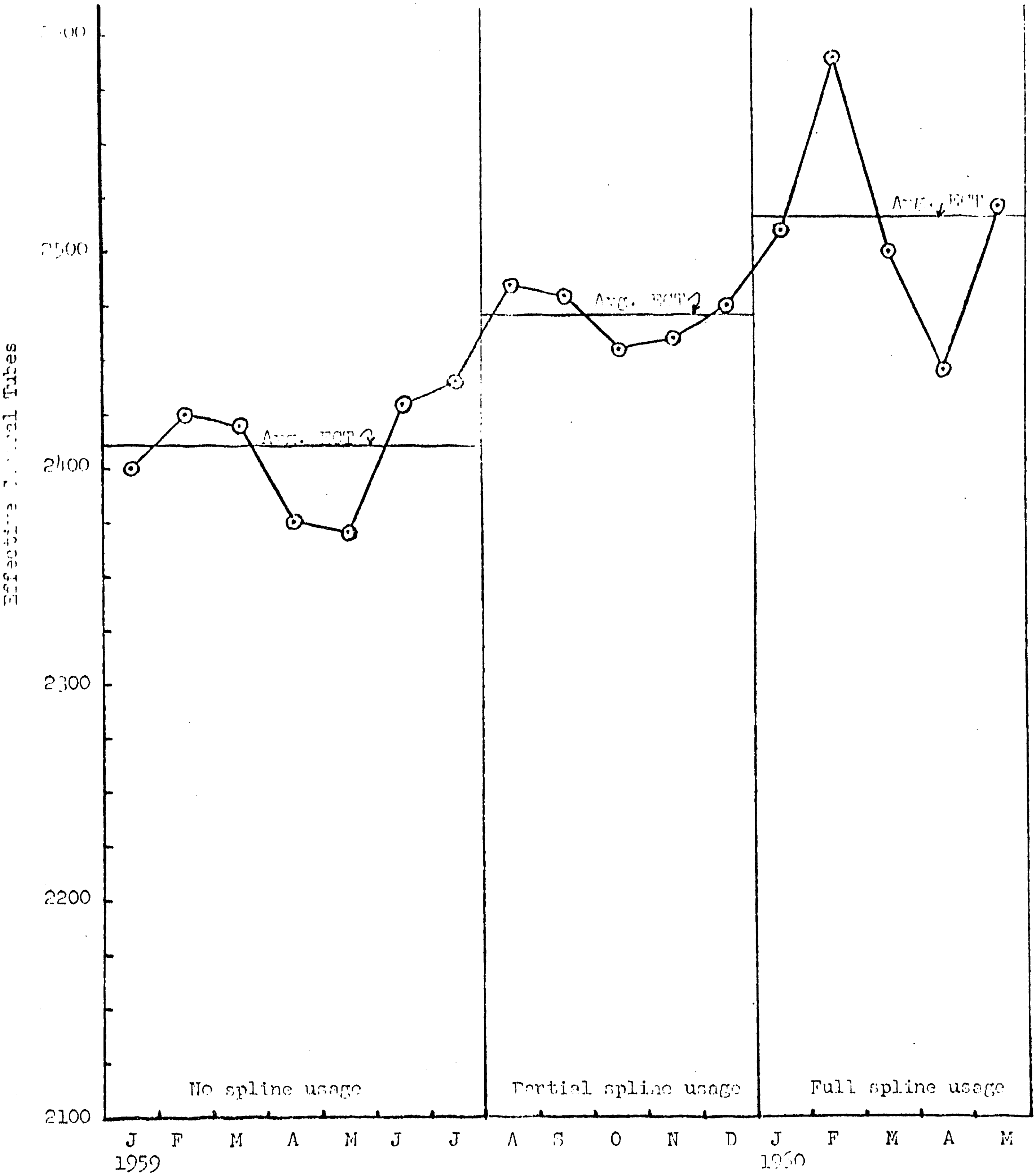

Figure 6

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TOTAL PERFORMANCE IMPROVEMENT

$$\frac{(LOE \times ECT)_{\text{with splines}}}{(LOE \times ECT)_{\text{pre-spline}}}$$

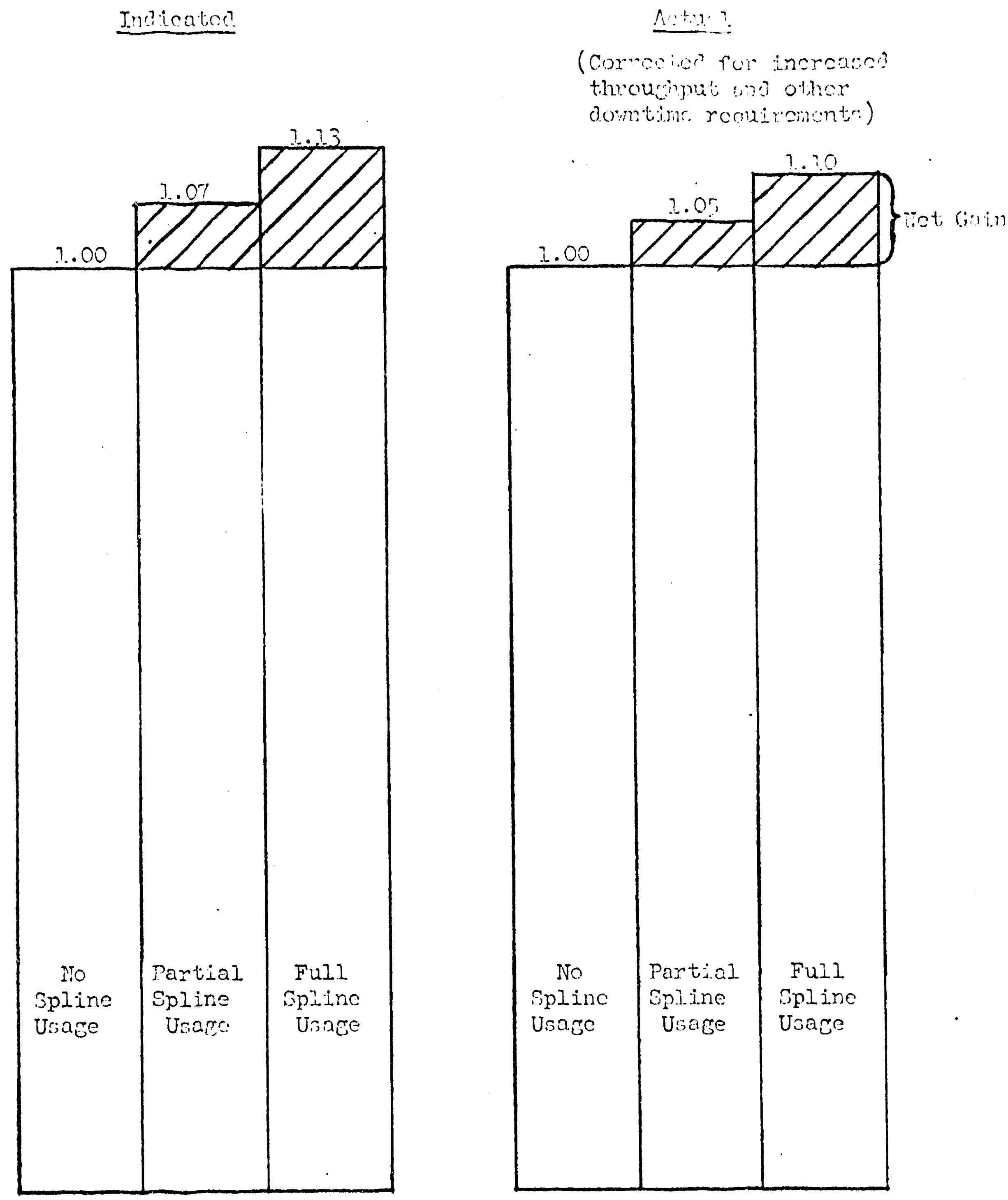

Figure 4

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DISCUSSION

The Poison Spline Supplementary Control System was first used effectively at KE Reactor in August, 1959. Full scale use of the system, especially for improving startup efficiency, was not possible until after an adequate spline removal system was applied in December, 1959. The benefits achieved with splines have also been a function of experience. Probably about 90 per cent of the potential benefit from the spline system at current power levels has been achieved. Optimum use will be attained with further experience.

The production gains made are divided into three categories: (1) Flux distribution control, (2) Startup efficiency, and (3) Flattening efficiency.

(1) Flux Distribution Control

In spite of increased power level and flattening, both of which increase flux cycling tendencies, shutdowns because of flux distribution control problems have been virtually eliminated. Longitudinal and radial flux cycling problems which forced power level reductions a year ago have been handled quite effectively with splines. Long term reactivity gains have been absorbed with poison splines, thus permitting long periods of operation which are not limited by control considerations. Without splines long term gains would force shutdowns for reactivity adjustments after two to three weeks of continuous operation. The gains achieved from improved flux distribution control are partially reflected in the improved level operated efficiency and flattening efficiency.

(2) Startup Efficiency

The benefits in this category are best shown by a comparison of non-equilibrium losses per startup or by the change in level operating efficiency /1/ (see Figures 1 and 2). The average non-equilibrium loss per startup for one year prior to the use of splines was equal to 1.0 day of production at the average equilibrium operating level. Present non-equilibrium losses average about thirty per cent of a current equilibrium day's production. Losses as low as 0.20 of a day have been attained. Without splines the current loss per startup would have increased to about 1.1 days of current equilibrium production because of the fact that non-equilibrium losses accelerate with increases in power level. Therefore, the gains achieved amount to approximately 0.8 days of current equilibrium production per startup.

Level operated efficiency, normalized to 2.5 outages per month, increased from 89 per cent before splines to about 92 per cent with partial spline usage during the period from August to December of 1959. With nearly full spline usage during the first five months of 1960 the level operated efficiency has averaged about 96 per cent (see Figure 2). Experience during the past months indicates that with full spline usage the level operated efficiency should average about 97 to 98 per cent. Since these values have been normalized to a single outage frequency (2.5 outages per month), efficient use of poison splines to supplement reactor control for startups and flux distribution control has been

/1/ Level operating efficiency is defined as follows:

$$\text{L.O.E.} = \frac{\text{Production for Month}}{\text{Days Operated in Month Times Average Maximum Level}}$$

[redacted]

DISCUSSION (Continued)

(2) Startup Efficiency (Cont'd)

the sole factor responsible for this gain. Because of the power level increase due to tube power increases alone, the level operated efficiency at this time would have been reduced to 87 per cent without splines.

Level operating efficiency improvement includes the production gain from the decrease in the number and size of power reductions caused by flux distribution cycling. This gain has also been a direct result of spline usage.

(3) Flattening Efficiency

The benefits of poison splines for flattening (power level is directly proportional to flattening for a maximum specific tube power) are best illustrated by comparing the effective central tubes (ECT) prior to and during the use of poison splines (see Figure 3). The average ECT in the seven months before splines were used was 2410. The average ECT during the last five months of 1959 was 2470, and during the first five months of 1960 the average was 2515. This represents an increase of 2.5 per cent and 4.3 per cent, respectively, over pre-spline operation.

Because the improvements in flattening and level operating efficiency are multiplying effects (more time is spent at equilibrium when level operating efficiency is high, and therefore, ECT becomes more significant), the ratio of the product of these two factors, with and without splines, is used to determine the production gain. Because of the increase in outage time associated with increased production and spline work the actual production gain is shown as about 80 per cent of the indicated gain (see Figure 4).

Without splines, the product of level operated efficiency and flattening would have been reduced about three per cent because of tube power increases during the past ten months. Therefore, the gains shown in Figure 4 are undoubtedly conservative.

When operating on a bulk effluent temperature limit, where tube powers are not limiting, the production improvement from increased flattening efficiency could be small. However, the level operated efficiency gain is a function of both the equilibrium power level and the startup efficiency. The latter would continue to be dependent on the available supplementary control. Actually, the total production gain from splines could be even higher under bulk limits with few ruptures, because without supplementary control operating periods might be restricted to two or three weeks by long term reactivity gains.

The poison column control facility is the only other supplementary control system that has been used sufficiently to evaluate. It is estimated that less than half the production improvements attained with the spline system could be achieved with PCCF columns, primarily due to the less favorable location flexibility and smoothness of control, production loss in tubes taken out of service, and the enrichment required to support the base reactivity cost of PCCF columns.

F. C. Franklin

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