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INSTRUMENTATION STUDIES
STATUS REPORT II
(HIGH LEVEL AND RATE-OF-RISE)

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INSTRUMENTATION STUDIES - STATUS REPORT II
(High Level and Rate-of-Rise)

INTRODUCTION

The purpose of this document is to present the latest results of a continuing instrumentation study being conducted by Research and Engineering. The qualitative aspects, basic criteria, assumptions, and digital and analog computer programs of the study are discussed in references 1 and 2.

In reference 1, results of 1- and 6-node calculations, for percentage- and fixed-temperature-trip instrumentation were presented. These results were used to obtain a general understanding of the problem and to assess the value of using a multinodal approach. Calculations to determine the amount of protection provided by linear rate and period instrumentation were not performed at that time. Thus, the results in reference 1 are limited in that they cover only a part of the possible nuclear safety instrumentation.

The previous results indicated that the multinodal approach should be used in analyzing high level and intermediate instrumentation. The results presented in this report were obtained from an 11-node model covering percentage- and fixed-temperature-trip instrumentation, and also linear temperature rate-of-rise and linear power rate-of-rise. Other specialized cases were also investigated. In particular, data were obtained to provide:

1. Eleven-node results for the old reactors.
2. Results for the K reactors comparable to those previously obtained for the old reactors, and results using parameters chosen for the high speed scanner project.
3. Linear power-rate-of-rise at the high levels.
4. Comparison between 6- and 11-node models.
5. The number of zone temperature indications required for good protection.
6. Safety parameters for the xenon-override enriched core.

This report also includes a section on data used in the analysis and equations for calculating data when it was not available experimentally. It should be emphasized here that before taking data from the curves given in this report, the authors should be consulted to be sure that the results are applicable.

It was mentioned previously that the instrumentation study is a continuing one. Although this report covers much of safety instrumentation used in the equilibrium or near-equilibrium power range, instrumentation used in the lower power ranges is yet to be analyzed. There also remains work to be done on incorporating two-phase flow calculations* into the program and analyzing some second order effects, due to the one-dimensional analysis, to ensure they do not affect the results appreciably.

*After publication of reference 1, comments were received from Thermal Hydraulics./3/ Basically, they felt that using the heat transfer equations given in that report led to a great deal of overconservatism in the results. They felt that two-phase flow calculations would describe the situation more completely and the results would be closer to the actual situation.

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SUMMARY AND CONCLUSIONS

For the old reactors the results of the 11-node calculations for percentage and fixed temperature trips are similar to but somewhat more restrictive than those given for 6-node results in reference 1. Limit curves were also obtained for a linear power rate-of-rise instrument with trips of 150 and 300 megawatts per minute. With both of these systems assumed to be in the safety circuit protection would be provided against the maximum ramp considered from very low levels up to equilibrium.

In general, the K reactor results are similar to those of the older reactors except in absolute magnitude, and one can draw the same conclusions concerning the degree of protection for percentage and fixed temperature trips as in reference 1 for the old reactors. (In that study it was indicated that percentage trips with a 110 per cent setting would be very effective provided that assumptions on stable reactor flux distribution geometry were valid. A 130 per cent trip, which corresponds more closely to the actual degree of protection considering geometry factors, would not provide adequate protection.) A limit curve for temperature rate-of-rise is also given. The parameters used were those found in the proposed high speed scanner for the K reactors. The results indicate that this type of trip provides adequate protection from one-eighth equilibrium level to equilibrium for trip values which would not be disadvantageous in operation.

The results obtained from the 11-node model indicate that not much is to be gained by addition of more nodes to the existing program. The largest gains in defining the degree of protection more specifically can be made by 1) incorporating the suggestions of J. M. Batch and E. D. Waters for consideration of two-phase flow into the present program, and 2) by attempting an analysis of second order effects in the other two dimensions, particularly those in the axial direction.

Several cases were run to determine the minimum number of RTD's required for adequate protection. From the results obtained one can say that the present number found in the ZTM (Zone Temperature Monitor) is fully adequate.

Limit curves for a bell-shaped flux distribution, which is typical for the xenon-override loading (with compensating poison withdrawn), were also calculated for use with a percentage trip instrument; these curves were found to be somewhat more restrictive than for the skewed flux distribution case.

ANALYSIS OF DATA

I. Old Reactor Results

The ramps used for determining the amount of protection a system provides are the same as those in HW-72591; a summary of the results is shown in Table I. For 21C inlet it is noted that a percentage trip instrument such as the high level flux monitor provides adequate protection for 110 per cent trip for all reactivity insertions. For 130 per cent this instrument gives protection over a range which does not include equilibrium. As in previous calculations the ZTM, with fixed temperature trip, does not give an adequate range of protection for reactivity insertions of 0.6 or 0.46 mk/sec. However, for 0.32 and 0.28 mk/sec the range is adequate.

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The results in Table 1 are not significantly different from the results obtained from the 6-node model. Figure I shows that at higher levels the results of the 6- and 11-node analog program tend to converge. Difference in ZTM results between the 6- and 11-node cases is somewhat larger than in the case of percentage trips; the 11-node results are again more restrictive.

Some of the points on the fixed-temperature-trip curves included in this report were obtained from 1- and 6-node results. Points obtained from the 11-node model were compared with 1-node results and it was found that they differed by a constant factor. Missing points were then obtained by multiplying the 1-node results by this factor. The 6- and 11-node results were also compared and again found to differ by a constant factor thus enabling the calculation of missing points. These points agreed with the points calculated from the 1-node model. In calculating these missing points one must be sure that one uses the particular 1- or 6-node results which have the same parameters as the 11-node results.

For a LOC inlet the results in Table 1 show that for the maximum reactivity insertion considered the high level flux monitors provide adequate protection, over an adequate range of power even for a 130 per cent trip. It must be remembered that only the inlet temperature was changed for these calculations; all other parameters remained the same. (In actual practice the reactor coolant flow would be reduced in the LOC case.) Table 1 also shows that ZTM protection is improved for a LOC inlet. Even for the large ramps the range of protection is quite adequate. It should be remembered that these results apply for full eight pump flow. If flow were decreased for the LOC inlet cases the results are expected to be about the same as for 21C inlet cases.

II. K Reactor Results

Two cases have been considered for the K reactors, one in which a maximum local reactivity ramp of 0.2 milli-k per second is inserted into the peak of a skewed vertical distribution and one in which 0.4 milli-k per second is inserted into the peak of a vertical cosine distribution. The 0.2 milli-k per second was arrived at by calculating the local effect of two rods and assuming both could be pulled at once at a rate of 7.2 inches per second. The 0.4 milli-k per second was obtained by calculating the local effect of the withdrawal of four rods simultaneously. No runs were made using a cosine distribution in the top-to-bottom direction; however, the authors feel that the results of pulling four rods from the peak of a cosine distribution would be about the same as pulling four rods from the peak of a skewed distribution.

A. Fixed Temperature Trip

Figure II is the limit curve for fixed temperature trips of 125C and 130C. The curves were obtained using a skewed distribution and parameters of the high-speed scanner system. For a 125C trip and a local reactivity insertion of 0.2 milli-k per second (half of what is physically possible) the range of protection is from 800 to 1775 kw (tube power) which is quite adequate for present operating conditions. For the 130C trip the much smaller range shown in the figure may not be adequate. For a ramp of 0.4 milli-k per second neither trip point gives good protection except at near-equilibrium tube powers; thus, the fixed temperature trip does not provide adequate protection, over sufficient range, for the current maximum physically attainable ramp.

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Table 1

SUMMARY OF OLD REACTOR RESULTS

Percentage Trip Setting	Fixed Temp. Trip Setting	Rate of Local Reactivity In- sertion - mk/sec.	Lowest Tube Power Protected*	Highest Tube Power Protected	Inlet Temp- erature C
110%	-	0.60	< 200 kw	1425 kw	21C
130	-	0.60	< 200 kw	1140 kw	21C
	125C	0.60	1230 kw	1450 kw	21C
110	-	0.465	< 200 kw	1430 kw	21C
130	-	0.465	< 200 kw	1145 kw	21C
	125C	0.465	1100 kw	1450 kw	21C
110	-	0.32	< 200 kw	1430 kw	21C
130	-	0.32	< 200 kw	1145 kw	21C
	125C	0.32	750 kw	1450 kw	21C
110	-	0.28	< 200 kw	1430 kw	21C
130	-	0.28	< 200 kw	1150 kw	21C
	125C	0.28	600 kw	1450 kw	21C
110	-	0.60	< 200 kw	1650 kw	10C
130	-	0.60	< 200 kw	1340 kw	10C
	114C	0.60	750 kw	1770 kw	10C
	119C	0.60	880 kw	1770 kw	10C
110	-	0.465	< 200 kw	1650 kw	10C
130	-	0.465	< 200 kw	1340 kw	10C
	114C	0.465	250 kw	1770 kw	10C
	119C	0.465	700 kw	1770 kw	10C
110	-	0.32	< 200 kw	1650 kw	10C
130	-	0.32	< 200 kw	1340 kw	10C
	114C	0.32	< 200 kw	1770 kw	10C
	119C	0.32	< 200 kw	1770 kw	10C
110	-	0.28	< 200 kw	1650 kw	10C
130	-	0.28	< 200 kw	1340 kw	10C
	114C	0.28	< 200 kw	1770 kw	10C
	119C	0.28	< 200 kw	1770 kw	10C

*200 kw was lowest power considered in the studies.

B. Percentage Trip

Figure III gives the limit curves for a percentage trip instrument. The results for ramps of 0.2 and 0.4 milli-k per second are practically the same as for the old reactors; i.e., for 110 per cent trip the instrument provides good protection in the top decade of power and for 130 per cent trip there is protection in this decade but not at equilibrium powers. Again we have the case that as long as procedures are followed and the instruments are set to trip at 110 per cent, a percentage trip instrument provides adequate protection, but when procedures fail there is inadequate protection beyond three-quarter equilibrium power.

C. Rate of Temperature Rise Trip

An integral part of the high speed temperature scanner is the temperature rate-of-rise feature. The rate-of-rise limit curves for this instrument

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are shown in Figure IV. Many of the features of this type of trip, which will be discussed are shown by these curves. For a ramp of 0.2 milli-k per second and a trip value of 0.4 degrees per second (which is equivalent to a rate of approximately 1000 megawatts per minute), protection is provided from levels at which temperatures become significant to 1959 kw. For a maximum ramp of 0.4 milli-k per second the upper level is reduced to 1800 kw. Reference to Figure II shows that both of the fixed temperature curves would be contained within the curve for the 0.4 degree per second trip; thus, the fixed temperature and rate trip would form an integral system, to be described, without any lapse in the over-all protection.

III. Linear Power-Rate-Of-Rise

Several runs were made in which a power-rate-of-rise instrument was simulated. Temperatures from nodes 3, 4, 5, 6, and 7 were averaged and this average temperature signal was then applied to circuits which simulated the power rate instrument. A skewed flux distribution was used with the peak in node 3. All reactivity ramps were inserted in this node. Limit curves are shown in Figure X, and the curves are for trips of about 150 and 300 megawatts per minute. Notice that even for the highest ramp considered for the old reactors one appears to have adequate protection for both 150 and 300 megawatt per minute trips. However, the power-rate-of-rise curves should be double valued; i.e., at an initial level of 1200 kw there will be two ramps for which the limit is not exceeded. If the initial level is 1200 kw, it would be possible to get a ramp which is slow enough that it would take a considerable amount of time to get to trip, and during the long interval enough energy could be put into the water to raise the outlet temperature above the limit. If the curves are double valued many interesting situations arise. These situations can be best illustrated by reference to the following diagram in the following discussion:

Diagram 1

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That portion of the plane which is shaded is the region in which a power-rate-of-rise instrument gives protection. Let us first consider that the maximum reactivity insertion is given by point #1. In this case the rate instrument provides protection up to Power Level A. Above level A, for ramp #1 and in the region below level A and to the left of the shaded area for ramps less than #1, lies the unprotected regions. In this unprotected region while the ramp is large enough to cause excess heat generation, it is small enough so that the instrument does not reach the trip point soon enough. If maximum ramp is that given by point 2, a rate instrument will protect the reactor for levels up to C. Again, however, any combination of ramp and initial level which falls to the left of the shaded area and below a line drawn from C to the curve is not protected by rate instrumentation. In this area the reactivity insertion is less than maximum. When the maximum reactivity insertion is that given by number 3 the rate instrument provides protection, for this maximum ramp, up to level B. As in the above case, the region defined by the curve and level B is unprotected. The instrument gives no protection, at any level, for the maximum ramp number 4. From the above discussion we thus see that with a power rate-of-rise instrument one must not only worry about the maximum reactivity insertion but also reactivity insertions which are not large enough to cause a trip in time.

When a power-rate-of-rise instrument is used in conjunction with a fixed temperature trip instrument, such as the ZTM, the above problems can be overcome. Other problems can arise in this case, however, if the choice of parameters which dictate the shapes of the curves are not properly chosen. Diagrams 2 and 3 show hypothetical limit curves for the power rate and fixed temperature instruments and the regions in which each provide protection. Double hatched areas are areas in which both instruments provide protection. Referring to diagram 2 we see that the combined fixed temperature and rate trips provide a great deal of protection and one is not bothered by reactivity insertions which are too low for the rate meter. Diagram 3 represents another combination of rate and temperature instrumentation but with different parameters. Here again the over-all region of protection is good. There is one region, however, which is unprotected and may give trouble. In the unhatched region, at the bottom left of the diagram, we have an area in which reactivity insertions are too small for rate instruments and too large for a fixed temperature device. Therefore, although an instrument which acts in conjunction with the rate instrument can overcome its drawbacks, one must be sure a situation such as that illustrated in diagram 3 does not develop.

From the available data the authors believe that with proper choice of trips the above situations will not occur. Data show that as the rate trip becomes large one is more likely to encounter the situation shown in diagram 3. Thus, rate and temperature trips must be adjusted so that operation is not hampered and no loopholes are left in reactor protection.

The situation can also arise where a fixed temperature trip by itself will not provide protection against the maximum credible ramp, but a combination of the fixed trip and a rate-of-rise trip can provide protection throughout the MW range of operation. In this case the rate trip gives protection for large ramps and the fixed temperature trip protects against the slow rates. This is illustrated in Diagram 4 where the fixed temperature trip curve is enclosed by the rate curve. Protection is provided up to level A in Diagram 4 where the maximum ramp is given by B. Level C is the equilibrium level and level A is the level equivalent to the fixed temperature trip.

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Diagram 2

Diagram 3

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Diagram 4

IV. Comparison of Results 6- and 11-node Models

When the instrumentation study was begun, see reference 2, the space-independent kinetic equations were used to describe the dynamic behavior of the reactor. The authors realized at the time that in the majority of the cases to be considered this description was not adequate and the initial calculations were used to determine general characteristics of the simulation and the effect of various parameters. The next reactor and instrumentation model was adopted from Miller's speed-of-control model,^{/4/} and was a 6-node model; i.e., the reactor was divided into six nodes in the vertical direction and the dynamic behavior of each node was described by the space and time dependent kinetics equations. The 6-node model was not quite adequate since if the reactor were divided into six equal nodes the bottom node, in which the flux monitors were located, was too large. If the size of this node was reduced the remaining nodes were too large and the description of the flux distribution and reactivity insertion suffered. It was decided that as many nodes as possible should be obtained with the available analog equipment. By using the well-known, one-amplifier simulation of the kinetics equations,^{/5/} for three delayed neutron groups, enough equipment was obtained to program for five extra nodes. With the extra nodes the problem described above was considerably improved.

Comparison of 6- and 11-node results is made only for the old reactors; analysis of the K reactors was never made with the 6-node program. For the percentage-trip comparison, the important parameters are:

- 1 - trip 110%
- 2 - delay - 0 seconds
- 3 - flux - cosine
- 4 - T_{in} - 21C
- 5 - limit - 150C

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For the fixed-temperature-trip comparison, the parameters are:

- 1 - trip - 125C
- 2 - delay - 0 seconds
- 3 - flux - cosine
- 4 - T_{in} - 21C
- 5 - limit - 150C
- 6 - time constants - $1/\lambda_3 = 1/\lambda_4 = 1.5$ seconds

where $1/\lambda_3$ and $1/\lambda_4$ are time constants associated with water transport and RTD heating respectively.

The only known differences between the 6- and 11-node comparison runs are the node spacing and K_m (the metal coefficient). For the 11-node model $K_m = K(T_m + 273)^{1/2}$ and for the 6-node $K_m = K_1(T_m + 273)^{-1/2}$ where $K = 2K_1$. The latter is not correct but is more conservative (i.e., less K_m feedback); therefore the difference between 6- and 11-nodes would be greater than shown by the curves if the same K_m were used.*

Figures I and V show that the maximum allowable ramps are lower for percent trips on flux and fixed temperature trip for the 11-node cases. Thus the previously published results^{2/} appear to be nonconservative within the assumptions used for the calculations. Referring to Tables 2 and 3, it is seen that for the percent-trip comparison neither the difference nor ratio of the ramps are a linear function of initial level. In the equilibrium region, 800-1300 kw, the difference in the ramp is small but nevertheless significant.

Table 4 shows that difference between the 6- and 11-node fixed-temperature trip results seems to be more linear. It has been shown that it is possible to calculate 11-node results from 6-node results. However, since the 11-node model is now operating, this is not too practical.

From the results of the 1-, 6-, and 11-node models one could say that increasing the number of nodes beyond 11 would cause a further decrease in maximum ramp for a given initial level. This is true because the finite difference approximation becomes better as the node spacing is decreased; i.e., the true values are approached asymptotically as the number of nodes is increased. The 11-node program is one-dimensional and the gain in precision of the reactor and instrumentation simulation by a further increase in the number of nodes is probably small compared to other possibilities for improvement. Obviously, the Hanford reactors aren't one-dimensional and a computer program which considers more than one-dimension and that has as well flow, pressure and improved heat transfer equations would be a better simulation of the reactor and instrumentation than the one-dimensional models. The improvement in the accuracy of the one-dimensional program by increasing the number of nodes can be easily checked when the IBM 7090 nodal program is completed.** An advanced program containing two-dimensional space dependent kinetics equation, hydraulic equations and improved heat transfer equations is presently being considered.

*The difference in the form of these equations was due to an error in assigning the proper exponent during integration.

**A multinodal digital computer program for performing kinetic studies is being developed by R. E. Tiller and C. A. Oster. A final report is to be issued when the program is complete.

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RESULTS FOR COMPARISON OF 6- AND 11-NODE MODELS

Table 2

<u>Initial Level</u>	<u>Max. Allowable Rate of Reactivity Insertion 6-node = R₆</u>	<u>Max. Allowable Rate of Reactivity Insertion 11-node = R₁₁</u>	<u>R₆ - R₁₁</u>	<u>R₆/R₁₁</u>
800	6.75	4.80	1.95	1.41
900	5.95	4.15	1.80	1.43
1000	5.15	3.50	1.65	1.47
1100	4.30	2.80	1.50	1.54
1200	3.35	2.10	1.25	1.60
1400	1.20	.40	.80	3.00

Table 3

<u>Rate of Reactivity Insertion</u>	<u>Max. Tube Power Allowable 6-node - R₆</u>	<u>Max. Tube Power Allowable - 11-node - R₁₁</u>	<u>R₆ - R₁₁</u>	<u>R₆/R₁₁</u>
0	1490	1440	50	1.03
1	1415	1330	85	1.06
2	1330	1210	120	1.10
3	1240	1070	170	1.16
4	1130	920	210	1.23

Table 4

<u>Initial Level</u>	<u>Max. Allowable Rate of Reactivity Insertion 6-node = R₆</u>	<u>Max. Allowable Rate of Reactivity Insertion 11-node = R₁₁</u>	<u>R₆ - R₁₁</u>	<u>R₆/R₁₁</u>
600	.36	.28	.08	1.29
800	.44	.35	.09	1.26
1000	.53	.44	.09	1.20
1200	.7	.58	-.12	1.21

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Equipment limitations prohibit putting more nodes into the analog computer program. Since this program has served to obtain basic answers and allow the authors to get a feel for the problem it is felt that detailed answers can be obtained faster using the digital program. This program will handle up to 100 nodes and can be used to test the hypothesis that beyond 11 nodes the increase in accuracy is marginal. Secondly, as mentioned above, the program will provide a fast means for obtaining answers to the many yet unanswered questions.

V. Zone Temperature Monitor Detector Requirements

The curves in Figures VI, VII, and VIII were calculated using the 11-node model. The runs were made at an initial level of 1200 kw tube power and are for the old reactors. The program was set up so that reactivity ramps of various sizes could be inserted in node 3, the node in which the peak of the power distribution occurred. The trip was a fixed trip on temperature, 119C, and the maximum ramp permissible was found when the trip function was placed in various nodes. The distances from node 3 to nodes 2 and 4, the nodes on either side of node 3, are equal; i.e., 128 cm or approximately six lattice units. Node 1 is 180 cm and 5 is 225 cm from node 3. Figure VI shows that for tube powers of 1200 kw in node 3 the tube powers in nodes 2 and 4 are 1190 and 990 kw respectively, thus showing the skewing to the top. The tube powers in node 1 are 1080 kw. The maximum ramps allowable if the trip function is in nodes 1, 2, 3, and 4 are 0.4, 0.7, 0.84 and 0.2 mk/sec respectively. This is shown in Figure VII. The item of interest is the comparison of the initial power in nodes 3 and 4 and the maximum allowable ramps when the trip function is in these nodes. The large differences in maximum allowable ramps are due to the nonlinear relationship between maximum ramp and initial tube power.

What do these results imply concerning the maximum number of detectors? This may be shown best by an example. Suppose the largest, local, reactivity insertion rate which can be physically attained due to the flux distortion described above is 0.65 milli-k per second and that the reactivity is being inserted in node 3. Further, assume that the maximum tube powers are 1200 kw, the node spacing is that shown in Figure VIII, and that a scram occurs only when detectors in adjacent rows trip (coincident trip). If detectors are six lattice units apart and all RTD's and associated equipment is operating properly a ramp of 0.65 mk per second in node 3 would scram the reactor in time. If all RTD's in node 3 were in some way blocked so that no scram signal could be given then a ramp of 0.65 milli-k per second in node 3 would cause limits to be exceeded since although node 2 would trip in time neither node 1 or 4 would trip before limits were exceeded. Thus, for detectors spaced at intervals of six lattice units one cannot permit faults to happen which takes a row of detectors out of service. Another way of expressing this might be that with an RTD-spacing of six-lattice units, the faults which one can allow to happen are limited. The zone temperature monitor has detectors placed every three lattice units. For a three-lattice unit spacing there would be an extra node between nodes 2 and 3 and between nodes 3 and 4 on Figure VII. Although no data were obtained with a three-lattice unit node spacing, one can judge that for the example case given above that even if node 3 were lost, limits would not be exceeded since trips from the node between 2 and 3 and from node 2 would give a scram in time. From the results of these calculations it appears that the number of detectors required in a ZTM system will depend on these factors: 1) the flux distribution assumed for the worst case, 2) the coincidence trip arrangement,

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3) the variations in flow and power in a region, 4) the maximum credible ramp, and 5) the trip setting. The one-dimensional nodal model does not describe accurately the local distortion in the side-to-side direction (since reactivity is added uniformly to the slab). A two-dimensional model would give a more realistic description of the reactivity insertion and probably show greater limiting curves for the same reactivity ramp. The calculated results available to date are not sufficient to determine exactly the minimum number of RTD's required for a ZTM. The present RTD spacing (1 out of 9 tubes) on the ZTM appears to be adequate and will allow coincident trips and a limited number of RTD's to be out of service.

VI. Xenon-Override Results

Figure IX is a Beckman* percent trip limit curve for a bell-shaped flux distribution that is representative of the xenon-override flux distribution.^{76/} The kinetic and heat transfer equations used in the calculation were for natural uranium, so the curve only approximates the xenon-override case which contains an enriched uranium core.

The maximum number of rods which can be pulled out of the peak of the bell-shaped flux distribution is one at B Reactor, and its full pile strength, as measured in this flux distribution by A. D. Vaughn,^{77/} is 5 mk. One would also consider the case of pulling the two electric rods from node 4, and number 5 rod. The electric rods are half as fast as number 5 rod and their combined strength about equals that of number 5 rod. For the case of pulling number 5 rod only, we calculate that locally number 5 rod causes a reactivity insertion of 0.8 mk/sec in the core, assuming a removal rate of seven inches per second. The effect of A, B and 5-rod being withdrawn together would be conservatively approximated by a local ramp of 1.2 mk/sec on the center node.

From Figure IX we see that with a percent trip set at 110 percent, protection is provided to a level of 1370 kw for 5 rod and to 1300 kw for A, B and 5 rods. For a percent trip of 130 percent, the limiting level is 1140 kw for 5 rod and 1060 kw for A, B and 5 rods. The above limiting levels are somewhat more restrictive than those for the skewed flux distribution.

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*Under-pile chamber system in current use which employs Beckman amplifiers with manual range and trip settings.

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FIGURE I
Comparison of Percentage Trip Limit Curves for the Old Reactors
which were Calculated from the 6- and 11-node Computer Programs

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FIGURE II

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Fixed Temperature Trip Limit Curves for the Proposed K Reactor
High Speed Temperature Scanner

Percentage Trip Limit Curves for the K Reactors

FIGURE IV

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Page 18Limit Curves for a Linear-Temperature Rate-of-Rise Trip
for the Proposed Reactor High-Speed Scanner

FIGURE V

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A Comparison of Fixed Temperature Trip Limit Curves for the Old Reactors which were Calculated from the 6- and 11-node Computer Programs

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Bar Graph Showing Initial Tube Powers
Relative to Node 3 for an Old Reactor Simulation

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FIGURE VII

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Bar Graph Showing the Maximum Permissible Rate of Reactivity Insertion for a Page 21
Fixed Temperature Trip in Nodes N₁, N₂, N₃, and N₄, the Reactivity Insertion
in Node N₃, and Tube Powers of 1200 kw in Node N₂

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FIGURE VIII

Bar Graph Showing the Distance from Node N_3 to Nodes N_1 , N_2 and N_4

Node Number **DECLASSIFIED**

FIGURE IX

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Percentage Trip Limit Curves for the Old Reactors and a Vertical Flux Distribution which is Typical of that Found with an Uncompensated Xenon-Override Core Charged in the Reactor

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FIGURE X

Limit Curves for a Linear-power-rate-of-rise Trip for the Old Reactors

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Percentage Trip Limit Curves for the Old Reactors

FIGURE XII
Percentage Trip Limit Curves for the Old Reactors

FIGURE XIII
Fixed Temperature Limit Curves for the Old Reactors

FIGURE XIV

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Fixed Temperature Trip Limit Curve for the Old Reactors

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Fixed Temperature Trip Limit Curve for the Old Reactors

APPENDIX I

Kinetics Equations

The kinetics equations used in the 11-node analog program are given in reference 1. The parameters used in these equations are listed below. (Physics parameters are for hot pile.)

	BDF	K
Neutron mean lifetime, l_0 , seconds	$1.224(10^{-3})$	$0.996(10^{-3})$
Diffusion length, L^2 , cm^2	344	269
Geometric buckling, B^2 , cm^{-2}	$32.19(10^{-6})$	$26.135(10^{-6})$
Geometric buckling (X directions), B_x^2 , cm^{-2}	$8.49(10^{-6})$	$7.22(10^{-6})$
Geometric buckling (Y direction), B_y^2 , cm^{-2}	$15.21(10^{-6})$	$11.7(10^{-6})$
Resonance escape probability, p	.8834	.8623
Fermi age, τ , cm^2	322	303

Node spacing, cm:

ΔZ_{-1}	50.00	32
ΔZ_0	53.18	76.2
ΔZ_1	53.18	133.35
ΔZ_2	127.6	
ΔZ_3		
ΔZ_4		
ΔZ_5		
ΔZ_6		
ΔZ_7		
ΔZ_8	53.18	47.625
ΔZ_9	53.18	47.625
ΔZ_{10}	50.00	32

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The kinetics equations of the 11-node model contained three delayed-neutron groups. The three-group constants are found in reference 8 and the following equations, obtained from R. E. Tiller,⁴ were used to correct for exposure. The values given for K are for an exposure of 800 MWD/T and the values for BDF are 400 MWD/T.

$$(\beta_1)_e = \frac{\sum_j f_j V_j \beta_{1j}}{\sum_j f_j V_j}$$

$$(\tau_1)_e = \frac{\sum_j f_j V_j \beta_{1j} \tau_{1j}}{\sum_j f_j V_j \beta_{1j}}$$

where:

$(\beta_1)_e$ = fraction of total neutrons in group 1 for exposed uranium.

$(\tau_1)_e$ = half-life of the 1th group for exposed uranium.

f_j = fraction of fission occurring in isotope j.

V_j = number of neutrons released per fission for the jth isotope.

β_{1j} = fraction of total neutrons in group 1 for jth isotope.

τ_{1j} = half-life of the 1 group for jth isotope.

λ_1 = decay constant of the 1th group for exposed uranium.

<u>i</u>	<u>β_1</u> BDF Reactors	<u>λ_1</u>
1	.0001912	.01249
2	.002087	.03716
3	.003947	.66906
<u>K Reactors</u>		
1	.0001822	.01252
2	.002015	.03716
3	.003834	.67751

The average metal ($\bar{T}_{m1}$) are given by^{1/} $\frac{d \bar{T}_{m1}}{dt} = K_1 W_1 - K_2 \bar{T}_{m1} + K_3 \bar{T}_{w1}$

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$$\frac{d \bar{T}_{w1}}{dt} = K_4 \bar{T}_{m1} = K_5 \bar{T}_{w1} + K_6 T_{in}$$

where: $\bar{W}_1$ is the tube power in KW

T_{in} is the inlet water temperature

K 's are constant

The reactivity feedback in mk due to the Doppler effect is ^{1/}

$$(K_m)_1 = -K_7 \left[(\bar{T}_{m1} + 273)^{1/2} - (293)^{1/2} \right]$$

where: K_7 is a constant.

The values of the above constants used in the 11-node model are given in the following table.

<u>Constant</u>	<u>BDF</u>	<u>K</u>
K_1	0.0661	.0575
K_2	0.7238	.8322
K_3	0.7238	.8322
K_4	1.428	1.102
K_5	4.727	3.613
K_6	3.299	2.511
K_7	0.6504	0.7532

Vertical Safety Rod Function

The following table gives the time in seconds taken by the VSR's to reach the top of a node. ^{9/} The VSR strength assumed was 23 mk and 40 mk, respectively, for BDF and K reactors. ^{10/}

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<u>Node</u>	<u>BDF</u>	<u>K</u>
N ₀	.86	.47
N ₁	1.10	.62
N ₂	1.29	.83
N ₃	1.55	1.04
N ₄	1.82	1.22
N ₅	2.06	1.39
N ₆	2.30	1.55
N ₇	2.52	1.74
N ₈	2.74	1.99
N ₉	3.39	

Flux Distributions

The various relative flux distributions assumed for the 11-node calculations are given in the following table. The bell-shaped distribution was obtained from reference 6.

	<u>BDF Reactors</u>			<u>K Reactor</u>
	<u>Skewed</u>	<u>Cosine</u>	<u>Bell-shaped</u>	<u>Skewed</u>
N ₀	.7	.145	.0145	.4
N ₁	.88	.296	.040	.871
N ₂	.964	.440	.079	.998
N ₃	.975	.736	.183	.897
N ₄	.805	.932	.409	.675
N ₅	.560	1.000	1.000	.455
N ₆	.344	.932	.409	.298
N ₇	.223	.736	.183	.177
N ₈	.102	.440	.079	.078
N ₉	.066	.296	.040	.047
N ₁₀	.03	.145	.0145	.018

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Instrumentation Equation

The following equations were used for the K reactor Beckman system.

$$1/\lambda_5 \frac{dN_B}{dt} = N_{10} = N_B$$

where: $1/\lambda_5$ is the Beckman time constant, a value of 0.12 second was used./11/

N_B is output of Beckman

N_{10} is the flux in node 10.

The equations for the output of the RTD were the same as given in reference 1. A value of three seconds was used for $1/\lambda_1$./12/ This data was for C overbore geometry and $1/\lambda_1$ appears to be between two and three seconds. P. A. Carlson estimated from other information a value of three seconds for $1/\lambda_1$. The equation used for calculating the water temperature at the RTD is an approximation. The information on the relationship between the water temperature at the end of the fuel and at the RTD is limited. This relationship is dependent on transport by time of the water and the water mixing and heat transfer in the downstream dummy charge. The RTD time constant $1/\lambda_2$ is 1.5 sec. and 2.5 sec. for BDF and K reactors respectively./13/

The time constants T_1 and T_2 for the temperature rate of rise instrumentation at BDF reactors are 1 and 0.33 seconds respectively./14/ Due to lack of sufficient analog equipment the temperature rate of rise was not calculated correctly but was approximately in the following manner. For BDF reactors, an average T_0 was computed from nodes N_3 , N_4 , N_5 , N_6 and N_7 . This average T_0 was then used to compute T_1 , T_{rtd} , V_1 and V_2 .

The temperature rate equations used for K reactors are an approximation for the High Speed Scanner. The rate trip was on $\frac{dT_{RTD}}{dt}$ where T_0 was the average of nodes N_2 , N_3 ,

N_4 , N_5 , N_6 , and N_7 . The 0.8 sec. HSS delay time was also factored into the calculations as an increase in VSR drop time.

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