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WANL-TME-1267
September, 1965

Westinghouse Astronuclear Laboratory

POWER PERTURBATIONS IN
COUPLED REACTOR SYSTEMS

(Title Unclassified)

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OCT - 8 1965

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Sacramento, California

Attention: Mr. D. Vanica

Subject: WANL-TME-1267, "Power Perturbations in Coupled Reactor Systems"

Gentlemen:

This letter transmits copies of the subject report for your information. The report describes analysis methods and the model used to evaluate the power and flux tilting of a reactor core when subjected to asymmetric incident neutrons from an external source as in clustered nuclear engines.

In conjunction with the previous report, WANL-TME-1152, "Reactivity Coupling of Clustered NERVA Reactors", the study of nuclear interactions between adjacent reactors in a clustered array has been completed. This effort was conducted under Project NE 1840.

Respectfully,
Original Signed By
H. F. Faught
H. F. Faught
Program Manager
NERVA Nuclear Subsystem

CKK/jf

Enclosures (10)

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POWER PERTURBATIONS IN COUPLED REACTOR SYSTEMS
(Title Unclassified)

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INTRODUCTION

Neutronic interaction between clustered reactors manifests itself statically in two forms: reactivity coupling and flux perturbation. Each reactor in a critical clustered array would be subcritical if removed from the array. The amount of subcriticality, or the reactivity coupling, has been investigated for ROVER reactors by LASL^{1, 2}, analytically under Project NE 1840 at WANL³, and by Douglas.⁴

Each coupled reactor exhibits power perturbation or tilting due to the asymmetric incidence of neutrons on its surface from the neighboring reactors. The amount of tilting is more pronounced in close-coupled systems than in loosely coupled arrays. It is also greater in a large core than in a smaller core of similar composition. For large, NERVA II type reactors in a close-coupled system, the perturbation of the normal power distribution can be significant. The present study was undertaken to estimate the magnitude of the power tilting in coupled systems of NERVA II reactors.

METHODS

The basic method used in this analysis employs 9-group, S_4 DTK transport calculations in slab geometry. The use of slab geometry allows economic one-dimensional calculations, rather than two-dimensional r - θ calculations which would be required for a more realistic representation. The validity of the slab representation will be discussed later. Since the systems under consideration are subcritical, inhomogeneous solutions to transport equations are employed. In contrast to the standard eigenvalue solution, inhomogeneous solutions are completely determined by the source strength (i.e., no normalization constant). Unfortunately, the inhomogeneous solutions are extremely time consuming with fissionable material (or upscattering) because of the iterative solution technique. The machine time varies inversely with the amount of shut-down which restricts the range of practical consideration to cases subcritical (or coupled) by \$2 or more.

The models of the NERVA I and NERVA II cores are shown in Figure 1. These diametric transverses of the reactors are used directly in slab geometry. Evidence that the model is

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FIGURE 1 NERVA I AND NERVA II MODELS

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reasonable was first obtained from a criticality calculation. The fission density obtained is compared with the WANEF cold PAX measured distribution⁵ in Figure 2.

A reasonable representation of the drums as poison slabs centered in the reflector having the same absorption rate as the vanes⁶ was employed. The reactor was then "brought to critical" by adjusting the transverse buckling. This critical configuration constituted the base case; effective transverse dimensions were 123 cm and 152 cm for NERVA I and NERVA II, respectively. To simulate a coupled condition, the poison regions representing the vanes were moved inward. The amount the reactor should be subcritical for a given poison region position was known from prior cylindrical cases. Since in slab geometry the vanes appear on only two sides, further compensation must be made by adjusting the transverse buckling in order to obtain correspondence of shutdown for a given poison region position in the slab and cylindrical representations. Careful simulation is required because the position of the vanes affects the peripheral power distribution, while the total shutdown controls the gross tilting.

EXPERIMENTAL DATA

The LASL, KIWI-PARKA coupled reactor study included a brief investigation of flux perturbation¹. Fission detectors located 16.75 inches on each side of the core axis were used to determine the relative fission rates. The ratio of the source side fission rate to the opposite side fission rate for three values of shutdown are shown in Figure 3. A straight line fit indicates that linear interpolation of results obtained for large amounts of shutdown should yield conservative estimates of the tilting in the range of interest (0 to \$0.50 shutdown).

ANALYSIS

The approach used in the analysis is to verify the method by comparison to LASL data on NRX-A or KIWI type reactors, and extend the method to the larger NERVA reactor. Toward this goal, the first case was a suitably shutdown NRX slab reactor with a unit leakage spectrum source. From cylindrical results, it was known that moving the poison ring inward 4.13 cm resulted in \$3 shutdown. Moving the slab representation in to the same position yielded a shutdown of only \$1.75. An additional \$1.25 shutdown was obtained through addition of buckling. The results of this inhomogeneous, simulated \$3 shutdown calculation are displayed in Figure 4.

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FIGURE 2 COMPARISONS OF MEASURED AND CALCULATED
SLAB MODEL FISSION DENSITIES

NERVA I REACTOR

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FIGURE 3 FISSION DENSITY RATIO OF SOURCE SIDE
TO OPPOSITE SIDE DATA*

*From LASL KIWI-PARKA Measurements

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FIGURE 4 PERTURBED FISSION DENSITY OF NERVA I
REACTOR SHUTDOWN (\$3) WITH SOURCE ON RIGHT

To determine the degree of convergence of the power distribution, three consecutive cases were run using convergence criteria (ϵ) of 5, 2, and 1×10^{-4} . The results indicated that the $\epsilon = 10^{-4}$ solution should be accurate to better than five percent maximum with a tendency toward less tilting. Thus, this degree of convergence was employed for both the NERVA I and NERVA II solutions.

Derived from the perturbed power distribution is Figure 5 which shows the ratio of the power on the source side to the power at the corresponding point symmetric about the centerline. The interpolated LASL data is also shown on this figure and is in satisfactory agreement with the calculation. Figure 6 shows the ratio of the inhomogeneous to the drums in "critical" power distributions.

Similar calculations on NERVA II were performed. The poison slab was moved in 5 cm and sufficient buckling added to yield \$2.33 shutdown, the actual shutdown for that position in a similar cylindrical system. The results are displayed in the final three figures. Figure 7 shows the perturbed power distribution for a unit leakage source on a slab simulated NERVA II \$2.33 shutdown. Figure 8 is the ratio of source side to away side fission density. By linear interpolation, the maximum expected tilting for sample radii as a function of shutdown (or simulated coupling) is shown in Figure 9.

DISCUSSION AND CONCLUSIONS

The analysis is based on two premises:

1. The maximum tilting displayed by a coupled system may be reasonably represented by a slab geometry, inhomogeneous transport model.
2. Tilting is linear with shutdown.

The results shown in Figures 2 and 5 lend support to the first assumption and LASL data substantiates the second to the extent that linear interpolation should be conservative.

Close-coupled NERVA I and NERVA II systems would have reactivity couplings of about 45% and 10%, respectively, if two reactors were operating with their pressure vessels in contact. This is the maximum coupling that could be expected for present designs. Peripheral

FIGURE 5 COMPARISON OF CALCULATED NERVA I
FISSION DENSITY RATIO AND LASL
KIWI-PARKA MEASUREMENT (\$3 SHUTDOWN)

FIGURE 6 RATIO OF PERTURBED AND UNPERTURBED
POWER DISTRIBUTIONS FOR NERVA I

FIGURE 7 FISSION DENSITY OF NERVA II
SHUTDOWN 2.33 WITH SOURCE ON RIGHT

FIGURE 8 CALCULATED NERVA II FISSION
DENSITY RATIO (SHUTDOWN \$2.33)

FIGURE 9 FISSION DENSITY RATIO FOR NERVA II
AS A FUNCTION OF SHUTDOWN AT
VARIOUS CORE LOCATIONS

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power perturbations for this case would be a maximum of 16 percent for NERVA I and 10 percent for NERVA II. At the expected array separation of 33 feet, the reactivity coupling is about 0.8% for NERVA I and 0.3% for NERVA II. For this array, the power perturbation would be quite negligible (less than one percent).

An array of three or more reactors will, of course, lead to greater power perturbations. Presuming a linear aximuthal variation of power from the maximum (toward a reactor in the array) to the minimum, this problem could be handled in an approximate fashion by superposition. The basic degree of tilting can be estimated from the amount of coupling and the geometry of the array will dictate the superposition procedure.

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