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MASTER

CONTROL OF XENON INSTABILITIES

IN LARGE PWR'S

SEMI-ANNUAL PROGRESS REPORT

FOR THE PERIOD ENDING

MARCH 31, 1968

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PROGRAM DESCRIPTION

This program investigates the characteristics and control of spatial instabilities in large pressurized-water reactors (large PWR's), with particular emphasis on azimuthal xenon instabilities (x-y plane). The program consists of the following technical tasks:

Task EUXE-200 - Effect of Core Parameters on Spatial Oscillations

The aim of this task is to analyze the effect of variations in core design and operating parameters on the propensity for spatial oscillations, with emphasis on those resulting from xenon redistribution. Parameters to be analyzed include, but are not limited to, core dimensions, fuel and moderator temperature feedbacks, and power distributions.

Task EUXE-300 - Remedial Control Procedures

Under this task, two-dimensional x-y calculations will be performed to establish control methods and detector locations which will prevent divergent oscillations. Calculated results will be used to develop criteria for the application of remedial measures to large pressurized-water reactors.

Task EUXE-400 - Three-Dimensional Analysis

Under this task, either direct or synthesized three-dimensional calculations will be performed to further study spatial instabilities in large PWR cores with conditions conducive to oscillations. If a three-dimensional oscillation develops after perturbations have been introduced, selected remedial methods (as developed under Task EUXE-300) will be applied and evaluated. The unique characteristics of three-dimensional oscillations (if observed) will be identified and the criteria for the application of remedial measures will be developed.

PROGRESS SUMMARY

Major progress for the six-month period ending March 31, 1968 is summarized below:

The terminal report for Task EUXE-200 was published. The report is titled "Xenon-Induced Spatial Instabilities in Large Pressurized Water Reactors", and it describes the theoretical bases and the analytical methods which were used in this program to investigate the characteristics of free-running xenon oscillations, including extensive parametric and sensitivity studies, and comprehensive analysis of the limitations of available calculational techniques.

Under Task EUXE-300, Remedial Control Procedures, exploratory diametral calculations were completed. One x-y calculation with temperature feedback was carried out and the core was found to exhibit a converging oscillation. Thus, before proceeding, the core model will have to be modified to achieve instability. The modifications being considered are an increase in power density and a decrease in enrichment. New nuclear constants are presently being prepared for the unstable core model.

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DETAILED PROGRESS REPORTS

EUXE-100

PROGRAM MANAGEMENT

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This is the sixth in a series of technical progress reports on the U.S.-Euratom program titled "Control of Xenon Instabilities in Large PWR's". The preceding reports in this series are:

EURAEC-1721 WCAP-3680-1	"Control of Xenon Instabilities in Large PWR's, Technical Progress Report for the Period Ending September 30, 1966"
EURAEC-1781 WCAP-3680-2	"Control of Xenon Instabilities in Large PWR's, Quarterly Progress Report for the Period Ending December 31, 1966"
EURAEC-1830 WCAP-3680-3	"Control of Xenon Instabilities in Large PWR's, Quarterly Progress Report for the Period Ending March 31, 1967"
EURAEC-1880 WCAP-3680-4	"Control of Xenon Instabilities in Large PWR's, Quarterly Progress Report for the Period Ending June 30, 1967"
EURAEC-1925 WCAP-3680-5	"Control of Xenon Instabilities in Large PWR's, Quarterly Progress Report for the Period Ending September 30, 1967."

The following topical report has also been prepared under this program:

EURAEC-1974 WCAP-3680-20	"Xenon-Induced Spatial Instabilities in Large Pressurized Water Reactors"
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Program management is not discussed in this technical progress report, since separate reports emphasizing the administrative aspects of the program are published monthly for limited distribution.

EUXE-200

EFFECT OF CORE PARAMETERS ON SPATIAL OSCILLATIONS

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The work performed under this task was completed in the previous reporting period. The work is described in detail in the following topical report, the abstract of which is also presented:

Poncelet, C. G. and Christie, A. M., "Xenon-Induced Spatial Instabilities in Large Pressurized Water Reactors," WCAP-3680-20 (March 1968).

The characteristics of free-running xenon-induced spatial oscillations in large pressurized water reactors (PWR's) are investigated both from a phenomenological point of view and from the standpoint of the theoretical and calculational methods employed in their analysis. The digital simulation of spatial xenon instabilities with multidimensional, multi-group diffusion theory programs is investigated in detail. An extensive study of the effect of a finite, non-zero time-step length on calculated stability characteristics is presented, including a set of correlations which permits the extrapolation of digital calculations to effectively zero time-step length. The sensitivity of the digital results to the spatial mesh length, the energy mesh, and the treatment of temperature feedback effects is investigated. The effect of a non-zero flux convergence criterion on spatial xenon oscillations is investigated. A comparison is made of modal theory results and digital simulation calculations. The space-dependent transfer function formalism is employed in a number of analyses, including the effect of delayed neutrons and the effect of finite temperature feedback time lags.

The space-time characteristics of xenon-induced instabilities in the two-dimensional plane perpendicular to the direction of coolant flow are studied for a large variety of core sizes, power distributions and temperature feedback effects. The effect of perturbation size and location is evaluated. Extensive parametric and sensitivity analyses are performed, based on a modal expansion method. Parameters investigated are core size, power distribution, power level, power coefficient, fuel enrichment, Xe-135 absorption cross section, I-135 fission yield and direct Xe-135 fission yield. Parametric calculations with one- and two-dimensional diffusion theory programs are performed to corroborate the modal theory results.

REMEDIAL CONTROL PROCEDURES

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A. Summary

This report covers work in progress as well as work accomplished. The one-dimensional (diametral) transient analysis has been completed. One x-y calculation with temperature feedback was carried out and was found to have a converging oscillation. Consequently, work has been initiated to prepare a case with a sustained or diverging xenon transient so a meaningful analysis can be performed using control algorithms.

B. Diametral Analysis

The exploratory one-dimensional analysis of azimuthal xenon transients in large PWR's has been completed. The calculations were carried out on a finite slab of length 10.65 ft. with enrichments 3.2, 2.7 and 2.2 w/o, the high enriched fuel located in the outer region. The intermediate and low enrichments were "loaded" in a checkerboard-like pattern with the intermediate in the center position. There was no burnable poison in any of these calculations. The calculational model takes into account and corrects for the Doppler effect and for water density variations throughout the core.

Despite deficiencies such as improper leakage in extreme fuel assembly positions and incorrect effective fuel characteristics resulting from the non-uniform loading, these diametral calculations have been found very useful in demonstrating stability characteristics as a function of various core parameters. Thus, the one-dimensional analysis provides an inexpensive means for selecting core conditions such as power density, enrichments, dimensions, and moderator temperature coefficient, to be

used in the x-y calculations on all 11-foot core with temperature feedback and using control algorithms. The difference in machine-time requirements is typically 20:1 in favor of the one-dimensional analysis.

C. X-Y Analysis

The two-dimensional analysis of azimuthal xenon instabilities in an 11-foot diameter core with temperature feedback, using control algorithms, has been started. The main effort, however, has been to prepare and select nuclear constants for the analysis. A set of constants arrived at applies to a core with a power density of 84.5 kw/l and enrichments 3.2, 2.7, and 2.2 w/o. The core has burnable poison and a beginning of life critical boron concentration of 1200 ppm. A subsequent two-dimensional calculation was carried out using a half core model with symmetry about a principal axis. The system was perturbed by inserting a control rod in the outermost rod position available on the axis. The poison was removed after one hour at which time the flux distribution was sufficiently distorted to initiate oscillations. Two-hour time steps were used when studying the resulting oscillations. The above mentioned core exhibits a converging oscillations. Figure 1 shows peak radial hot channel factor versus time after perturbation and Figure 2 the hot channel factor on the axis of perturbation. Also included is a plot showing $F_{\Delta H}$ versus time from a diametral calculation having the same conditions as the x-y calculations. The moderator temperature coefficient in both cases is approximately $-0.5 \times 10^{-4}/^{\circ}\text{F}$.

No attempt was made to use any "external" control procedure in the above calculation as it is recognized that a more meaningful analysis would require the presence of a sustained or diverging xenon transient. Consequently, work has been started to prepare nuclear constants for a core having a higher power density, 100 kw/l, and lower enrichments, 3.1, 2.65, and 2.15 w/o, as the effect of these changes would enhance the xenon instability of the reactor.

EUXE-400

THREE-DIMENSIONAL ANALYSIS

This task was inactive during this report period.