Project 0272
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Westinghouse Atomic Power Divisions

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CONTROL OF XENON INSTABILITIES

IN LARGE PWR'S

QUARTERLY PROGRESS REPORT

FOR THE PERIOD ENDING

MARCH 31, 1969

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Prepared for the New York Operations Office
U. S. Atomic Energy Commission
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Reactor
April 1969

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SECTION 1

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:

1. 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.

2. 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.

3. 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.

SECTION 2

PROGRESS SUMMARY

Major progress for the three-month period ending March 31, 1969 is summarized below:

A preliminary copy of a topical report which describes in detail work performed under Task EUXE-300 has been sent to the AEC for review and approval.

Three-dimensional instability calculations, including feedback effects, were initiated this report period and are about 70% complete. The overall core geometry of the 3-D model is that of a typical 4-loop core with 193 fuel assemblies. Three homogenized enrichments and burnable poison zones were selected by running a series of two-dimensional calculations in which the fuel enrichments and the loading patterns were varied until an acceptable power distribution was found. In parallel with the three-dimensional analysis, a two-dimensional analysis was carried out and the results show that the average plane is stable while the inlet plane is not. A comparison will be made between the two and three dimensional results when the three-dimensional work is completed.

SECTION 3

EUXE-100

PROGRAM MANAGEMENT

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Development Projects
PWR Systems Division

This is the last 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"
EURAEC-2008
WCAP-3680-6	"Control of Xenon Instabilities in Large PWR's,
Semi-Annual Progress Report for the Period Ending
March 31, 1968"

EURAEC-2045 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-7 Quarterly Progress Report for the Period Ending
June 30, 1968"

EURAEC-2067 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-8 Quarterly Progress Report for the Period Ending
September 30, 1968"

EURAEC-2080 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-9 Quarterly Progress Report for the Period Ending
December 31, 1968"

The following topical reports have also been prepared under this program:

EURAEC-1974 "Xenon-Induced Spatial Instabilities in Large
WCAP-3680-20 Pressurized Water Reactors" March 1968

WCAP-3680-21 "Control Procedures for Xenon-Induced X-Y
Instabilities in Large Pressurized Water
Reactors" (to be issued)

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.

SECTION 4

EUXE-200

EFFECT OF CORE PARAMETERS ON SPATIAL OSCILLATIONS

G. H. Minton, Manager

Reactor Physics and
Mathematics Section

J. E. Olhoeft, Manager

Reactor Physics

C. G. Poncelet

A. M. Christie

The work performed under this task has been completed. 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).

Abstract

The characteristics of free-running xenon-induced spatial oscillations in large pressurized water reactors (large 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.

SECTION 5

EUXE-300

REMEDIAL CONTROL PROCEDURES

A. F. McFarlane, Manager

Nuclear Design
4 Loop Plants

F. B. Skogen

The work performed under this task has been completed. The work is described in detail in a topical report, the title and abstract of which are:

McFarlane, A. F. and Skogen, F. B., "Control Procedures for Xenon-Induced X-Y Instabilities in Large Pressurized Water Reactors", WCAP-3680-21 (to be issued)

ABSTRACT

Using digital simulation techniques, various methods were investigated for the control of xenon-induced spatial oscillations in large, pressurized water reactor (PWR) cores. The oscillations are studied in a three-zone core, eleven feet in diameter, in a plane at right angles to the coolant flow. It is shown that successful control can be achieved by a single insertion of one appropriate rod selected from a number of suitably located control rods. The effect of varying the duration and position of rod insertion is discussed, and various alternate control procedures are proposed and evaluated.

SECTION 6

EUXE-400

THREE-DIMENSIONAL ANALYSIS

A. F. McFarlane, Manager

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4 Loop Plants

F. B. Skogen

1. Summary

The three-dimensional analysis of xenon oscillations in a typical large PWR core, with feedback effects included, is about 70% completed. This report discusses the work accomplished to date and includes the results of a two-dimensional calculation run in parallel with the three-dimensional analysis. The core geometry is described along with a discussion of restrictions imposed by the calculational model.

2. Core Description

The reactor system selected for this study is a large PWR core with the fuel loading pattern shown in Figure 1. Slight modifications from a typical checker-board core are necessary due to restrictions imposed by the thermal-hydraulic model presently available in the three-dimensional code, and the relatively long computer running time necessary. The latter dictates a reduction in the spatial mesh intensity to a point where it is necessary to do the analysis on a homogenized core model; i.e., all non-lattice regions are homogenized in with the fuel. The geometry chosen has two mesh intervals per full assembly and a total of 12 equally spaced axial intervals in the active core. The X-Y mesh width used is about 10.8 cm, which was found to be adequate when studying free-running xenon oscillations.^{/1} The overall problem size is 40 x 20 x 18 including the baffle, upper, lower, and radial reflector regions; i.e., the core is described by a total of 14,400 mesh points.

^{/1} Poncelet, C. G. and A. M. Christie, "Xenon-Induced Spatial Instabilities in Large Pressurized Water Reactors," WCAP-3680-20 (March 1968).

Figure 1. The X-Y Flow Channel Geometry and Fuel Loading Pattern

The thermal-hydraulic model determines the flow and enthalpy rise in the various subchannels in the core as a function of the power distribution, and flow mixing between assemblies is allowed for. The main limitation encountered in this model is that the largest channel array that can be described is 9x9 and that does not allow at least one flow channel per fuel assembly in a 15x15 assembly core. Consequently, it is necessary to combine more than one (and as many as four) fuel assembly in each channel, and it becomes impossible to reproduce the identical checkerboard loading typical of large PWR's. Figure 1 shows the X-Y channel array selected.

The above geometry was arrived at by running a series of two-dimensional calculations in which the fuel enrichments and the loading patterns were varied until an acceptable power distribution was found. The enrichment set 2.4, 2.65, and 3.1 w/o was selected. The core has burnable poison distributed uniformly throughout with the equivalent of approximately six burnable poison pins per fuel assembly. With a critical boron concentration of 1,100 ppm, the resulting X-Y power distribution in a plane four feet from the bottom of the core, as shown in Figure 2, is relatively flat and compares favorably with that of a standard PWR design. The power density of the core is 104.5 w/cc.

Two-Dimensional Analysis

In parallel with the three-dimensional calculation a two-dimensional analysis on a core of identical geometry was carried out. The code was the same as the one used in the EUXE-300 study. Two calculations were performed; one investigated the behavior of an average plane while the other looked at the inlet plane. The results of this analysis show that while the average plane is stable, the inlet plane, which has no pointwise moderator density feedback, exhibits an unstable oscillation.

The reactor system was perturbed by inserting a local poison in the form of a control rod in the peripheral region of the core. The poison remained in the core for one hour and was then withdrawn. This is the same procedure as was applied in the EUXE-300 study. The reactivity worth of the perturbation was about 0.1% $\Delta\rho$.

2 1.044	3 1.179	4 1.165	5 1.220	6 1.152	7 1.220	8 1.165	9 1.179	10 1.041
11 .960	12 1.130	13 1.215	14 1.140	15 1.220	16 1.140	17 1.215	18 1.130	19 .960
20 .680	21 .951	22 1.017	23 1.215	24 1.165	25 1.215	26 1.017	27 .951	28 .680
29 .386	30 .729	31 .951	32 1.130	33 1.179	34 1.130	35 .951	36 .729	37 .386
	38 .386	39 .680	40 .960	41 1.041	42 .960	43 .680	44 .386	

Figure 2. X-Y Power Distribution In Plane No. 11
(4 Feet From Bottom of Core)

Figures 3 and 4 show the X-Y power peaking history as a function of time following the perturbation for the average and inlet plane, respectively. The stability indices of the two oscillations are $-.042$ (stable) and $+.037$ (unstable). A comparison will be made between the two and three dimensional results when the three-dimensional work is completed.

Figure 3. X-Y Power Peaking Versus Time After Perturbation
(104.5 w/cc, Half Core Symmetry, Average Plane)