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WCAP-3680-9

WCAP-3680-9

CONTROL OF XENON INSTABILITIES

IN LARGE PWR'S

QUARTERLY PROGRESS REPORT

FOR THE PERIOD ENDING

DECEMBER 31, 1968

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Project Engineer

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Prepared for the New York Operations Office
U. S. Atomic Energy Commission
Under AEC Contract AT(30-1)-3680

January 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 December 31, 1968 is summarized below:

A topical report describing in detail work under Task EUXE-300 has been completed in draft form and it is presently undergoing internal technical review.

Work continued on modifying the code ZEST to test the time-dependent flux expansion technique which corrects time-step errors in xenon redistribution calculations. However, this has been more involved than originally expected and it no longer appears possible to complete this work in sufficient time to utilize the results in 3-D studies. Thus, this investigation has been terminated in favor of proceeding directly with 3-D instability calculations, the preparatory stages of which are now in progress.

SECTION 3

EUXE-100

PROGRAM MANAGEMENT

M. J. O'Boyle, Project Engineer

Development Projects
PWR Systems Division

A. P. Suda

This is the ninth 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 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-1 Technical Progress Report for the Period Ending
September 30, 1966"

EURAEC-1781 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-2 Quarterly Progress Report for the Period Ending
December 31, 1966"

EURAEC-1830 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-3 Quarterly Progress Report for the Period Ending
March 31, 1967"

EURAEC-1880 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-4 Quarterly Progress Report for the Period Ending
June 30, 1967"

EURAEC-1925 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-5 Quarterly Progress Report for the Period Ending
September 30, 1967"

EURAEC-2008 "Control of Xenon Instabilities in Large PWR's,
WCAP-3680-6 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"

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

Various strategies for the control of xenon induced spatial oscillations in large PWR cores are investigated using digital simulation techniques. The oscillations are studied in a three zone core 11 feet in diameter, in a plane at right angles to the coolant flow. It is shown that successful control can be achieved by the 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

G. H. Minton, Manager

Reactor Physics and
Mathematics Section

J. E. Olhoeft, Manager

Reactor Physics

C. G. Poncelet

A. M. Christie

1. INTRODUCTION AND REVIEW

The analysis of xenon induced oscillations in multi-dimensional codes, particularly when temperature feedback effects are included, can be very time consuming. The present investigation is an attempt to reduce both the computation time and the error associated with the depletion of xenon over a finite time-step. For an account of the basic theory used in the analysis, the quarterly progress reports WCAP-3680-7 and WCAP-3680-8 should be studied. A brief outline is discussed below.

Knowing the flux, xenon and iodine distributions at any point in time, it is possible to calculate the higher derivatives with respect to time of these variables. This is done here by first linearizing the diffusion equation and coupled xenon and iodine equations and then differentiating them analytically n times. In this manner, a recursion relation is derived between the derivatives which can be used to build up successive higher derivatives from lower ones. In matrix form, these equations could be written as

$$Z^{(n)} = M Z^{(n-1)} \quad (1)$$

where $Z^{(n)}$ is the n^{th} derivative of the state vector for the flux, xenon, and iodine. This would be built up from $Z^{(0)}$, the corresponding fundamental distributions. In particular, if we know the flux derivatives in time we can expand this variable as a function of time around the point t_k by the equation

$$\phi(x,t) = \phi(x,t_k) + \sum_{i=1}^N \frac{(t-t_k)^i}{i!} \phi^{(i)}(x,t_k) \quad (2)$$

From this, the xenon can be more accurately depleted and a good source guess for the next time step be derived.

2. PROGRAMMING MODIFICATIONS

Modifications were made to the one-dimensional two-group code ZEST in order to test the effectiveness of the theory and to gain some insight into its practical value. The ZEST code was originally used to examine free-running xenon oscillations, and both the code and its results were reported under the EUXE-200 program in the report WCAP-3680-20. Reprogramming was required in two areas. These were in the calculation of the derivatives and the subsequent numerical integration of the xenon and iodine equations.

The modifications required to compute the flux derivatives are essentially the seven steps outlined on pages 16-17 of WCAP-3680-7. The only aspect not discussed there is the addition of an upscatter term in order to allow for a two-group model. This term did not require significant modification to the subroutine which originally solved the set of equations for the flux, since the method used was many line relaxation. However, more involved programming was later required in order to incorporate the equation which suppresses the fundamental flux distribution when the higher flux derivatives are being computed. This equation in effect equates the average power produced by the higher harmonics to zero. The theoretical basis for this equation is discussed in WCAP-3680-8.

The xenon and iodine equations were programmed using Equations 32 and 34-36 of WCAP-3680-8. The scheme allows the user to input the number of sub-intervals of time which are used to numerically integrate the xenon and iodine equations between time steps once the time dependent flux is obtained (Equation 2). The effectiveness of this method of solution has not yet been evaluated as debugging has not reached this subroutine.

After the required modifications were initially incorporated, a very simple seven-point reactor core model was set up to debug the code. It was subsequently found that the ZEST model had some errors resulting from inconsistencies in the relation between certain point-wise and mesh averaged quantities. An example of the kind of difficulty encountered occurred in the value of the xenon number density at a region interface. As this variable exhibits a discontinuity at the boundary, it has, when computed on a point-wise basis two values at the interface. This led to difficulties when those values were used in relation to cross sections defined on a mesh-wise basis. Subsequently, the code was modified so that all cross sections and number densities were defined on a mesh averaged basis. This eliminated inconsistencies of the type described above. The matrix coefficients used in the calculation of the flux were still however computed on a point-wise basis in order to give a point-wise flux and source. After the new source has been calculated, the flux was then averaged across each mesh block in order to compute such variables as xenon number densities.

These errors were not of great significance in the original ZEST code and resulted in an error in the flux of 1 per cent to 2 per cent. This is not the case in the calculation of higher derivatives. It is well known that, in general, the accuracy of calculating derivatives of a function numerically is very sensitive to the round-off error through loss of numerical significance. It is therefore of considerable importance to retain as many significant digits as possible in the calculation.

A similar problem is encountered with the convergence criterion. If the flux has a convergence criterion of 10^{-5} then the flux will only be accurate to five significant figures. In the calculation of each successive flux derivative, some of the significant places will be lost and a point will be reached where some higher derivative will be so dominated by round-off error that its value will be worthless. It is expected, however, that sufficient meaningful higher derivatives can be evaluated without having to impose too severe a convergence criterion such that the extrapolation can be carried out.

3. IMPLICATIONS OF THE METHOD

In developing this extrapolation procedure, application to multi-dimensional codes such as PDQ-07 has been the logical goal. Such codes as PDQ-07 have unfortunately no provision at present for fixed source problems, and it is only through such a capability that the Taylor series could be implemented. (A fixed source option would also have application to other important problems.) With a fixed source option it would be possible to incorporate the expansion by iterative means. This would involve including the effect of the up-scattering term in the source vector and iterating on this adjusted source which would be modified at each outer iteration.

The sensitivity of the derivatives sets a limit on the accuracy of the extrapolation procedure. Where the curvature of the flux is greater, more derivatives will be required for the same accuracy and hence a tighter convergence criterion might have to be set on the eigenvalue calculation at that point in time. A final limit will occur, independent of round-off, due to the fact that the equations were initially linearized. Hence the Taylor expansion for a large number of terms will converge to a slightly off-set value.

Because of the complicated interactions of the above operations it is difficult to assess accurately the importance of each individual effect. The simplest evaluation would be through some numerical calculations.

In conclusion, the development of the Taylor expansion procedure has been more involved than first expected. This has been due in part to small errors in the original ZEST code, a fact which has focused attention on the sensitivity of this kind of analysis to round off error. Developing the method for three dimensions (e.g., in PDQ-07) would involve considerable computer program development particularly when a temperature feedback is involved. Since the schedule is such that this work could not be completed in time for utilization in 3-D studies, this investigation has been terminated in favor of proceeding directly with 3-D instability calculations, of which preparatory efforts are under way.