DESCRIPTION OF PHYSICS DATA FOR CATHENA SAFETY ANALYSIS OF THE MAPLE-X10 REACTOR

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ABSTRACT

The transient safety analysis of the MAPLE-X10 Reactor has been performed using the thermalhydraulics code CATHENA together with either a point reactor kinetics model within CATHENA or a separate two-dimensional kinetics and thermalhydraulics calculation within the code TANK. This paper summarizes all the sources of reactor physics data supplied to CATHENA for the transient simulations. The physics methods used to obtain them and the underlying assumptions are discussed.

1.0 INTRODUCTION

The CATHENA [1] computer code uses a one-dimensional two-fluid thermalhydraulics model to describe the steam-water/noncondensable gas flow in a pipe. CATHENA is a coupled thermalhydraulics-point kinetics code and has been used to simulate the transient behaviour of the MAPLE-X10 Reactor [2]. The MAPLE-X10 Reactor is a small (10 MW_{th}) pool-type reactor intended for isotope production. It is light-water-cooled and moderated and the core is surrounded by a heavy-water reflector. CATHENA requires a great deal of reactor physics data in order to perform transient simulations. An extensive reactor physics program has been undertaken to generate these data. The physics data generated for the initial core and the equilibrium isotope production core include axial and channel powers, pin powers, reactivity feedback effects, neutron kinetics parameters, power deposition, decay heat power and external reactivity devices.

This physics contribution is important for several reasons. The safety review and licensing of the MAPLE-X10 Reactor could not be accomplished without verifiable transient analyses of postulated loss-of-regulation and loss-of-core-cooling accident scenarios. As well, the study of such transients is essential for confirming that reactor components and design will meet requirements. The physics contribution to the modelling of these scenarios is crucial, especially in regard to the effects of reactivity feedback in transient simulations.

This paper describes the calculation methods used to generate the required physics input to CATHENA. These methods include using the neutron transport lattice code WIMS-AECL [3] and the neutron diffusion code 3DDT [4] in modelling the MAPLE-X10 Reactor. Most

of the physics data are derived directly by these codes. The Monte Carlo code, MCNP [5], has been used for some benchmark comparisons of 3DDT results and for the calculation of details, such as short-range axial power peaks not calculable with other methods.

The paper also describes the channel powers, the axial power distribution obtained from 3DDT results, and the radial fuel-pin-power distribution obtained using MCNP. These are needed to determine the peak power ratings of the fuel and the margin of safety to critical heat flux (CHF).

A detailed discussion of the reactivity feedback mechanisms modelled in CATHENA is presented. This includes reactivity coefficients and the statistical weighting scheme used with them to predict reactivity feedback for distributed changes in fuel temperature, water temperature and water density/void. We also describe the neutron kinetics parameters, ^{135}Xe effects, power deposition, decay heat power curves, and external reactivity devices. Each has an important role in correctly modelling the physics aspects of the transient analysis of the MAPLE-X10 Reactor with CATHENA. An example is given of a CATHENA simulation showing the impact of reactivity feedback on a slow loss-of-regulation transient.

2.0 PHYSICS CALCULATION METHODS

2.1 The WIMS-AECL/3DDT Code Combination

The neutron transport code WIMS-AECL and the three-dimensional neutron diffusion code 3DDT are required to generate physics input data for the transient analysis simulations using CATHENA. WIMS-AECL provides a variety of geometric specifications for representing local regions of the reactor model in one or two dimensions. The WIMS-AECL models for the MAPLE-X10 Reactor regions are designed to reflect up-to-date specifications of the reactor design. They include a supercell region, external to the cell-of-interest, that provides a typical albedo* and neutron spectrum appropriate to the environment of the cell. The cross-section library used by WIMS-AECL is an 89-group library prepared from ENDF-B/V** data. Cross sections for the cell being modelled are produced with WIMS-AECL and may be selected for the cell-of-interest either within WIMS-AECL or external to WIMS-AECL. Utility codes collapse the neutron energy group structure to an appropriate number of groups for 3DDT calculations, perform fuel management simulations, and provide or plot data from the results of the 3DDT simulations.

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* The albedo is the ratio between neutron currents leaving and entering the cell at its boundary.

** Evaluated Nuclear Data File - Brookhaven, Version V.

These codes are used in obtaining axial power and flux profiles, reactivity coefficients and feedbacks, along with control rod worths for the CATHENA input.

2.2 The MCNP Code

MCNP performs a Monte Carlo calculation of neutron and photon transport by statistical analysis. The continuous energy cross sections for most materials are based on ENDF-B/V data.

The repeating geometry option is available in MCNP Version 3B and later versions. With this feature, the detailed modelling with MCNP of the entire MAPLE-X10 core and reflector has become practical. The full model has proved valuable in benchmarking WIMS-AECL/3DDT calculations [6] as well as providing a means to obtain detailed fuel element or pin powers.

2.3 The TANK Code

A multidimensional kinetics analysis is provided through the physics contained within the code TANK [7]. The kinetics model within CATHENA is a point kinetics model. This means that the fraction of reactor power in any spatial node is independent of time. TANK may now be linked with CATHENA in order to replace the point kinetics model contained within CATHENA or to assess the accuracy of using point kinetics. For the results discussed in this paper, only the point kinetics model within CATHENA is used.

TANK is also used to calculate certain reator physics data used as input to CATHENA. This includes kinetics parameters, decay heat power contributions and shutdown reactivity.

3.0 POWER DISTRIBUTION DATA

3.1 Channel Power Maps

A fuel management utility is used to process the output of 3DDT to provide data on the total channel powers in each fuel bundle of the MAPLE-X10 core. This information may also be obtained by MCNP. The agreement between the two codes depends on the choice of the 3DDT model [6]. The two codes generally agree to better than 4.5% in 36-element driver channel powers, and within 1.5% in k_{eff}, the neutron multiplication factor. Differences in channel powers are larger, ~12% for the other fuel channels using a coarse-mesh in the core region, but these decrease back to the 5% range when the mesh is made finer. For the purpose of CATHENA input, the MCNP model was used to provide pin and channel powers. The results of the channel power maps are given here for two MAPLE-X10 core models: the initial core, using MCNP, and the

equilibrium core, using 3DDT. The results of channel powers in the 19-site hexagonal core are shown in Figures 1 and 2.

Figure 1 shows the power map for the initial MAPLE-X10 core. This core contains ten 36-element driver bundles (DA1 to DA6, D1-D4), six 18-element control (C1-C3) and shutoff (S1-S3) bundles and three 12-element dual-section dummy assemblies (B1-B3). All channels contain fuel except for the ones containing dummy assemblies.

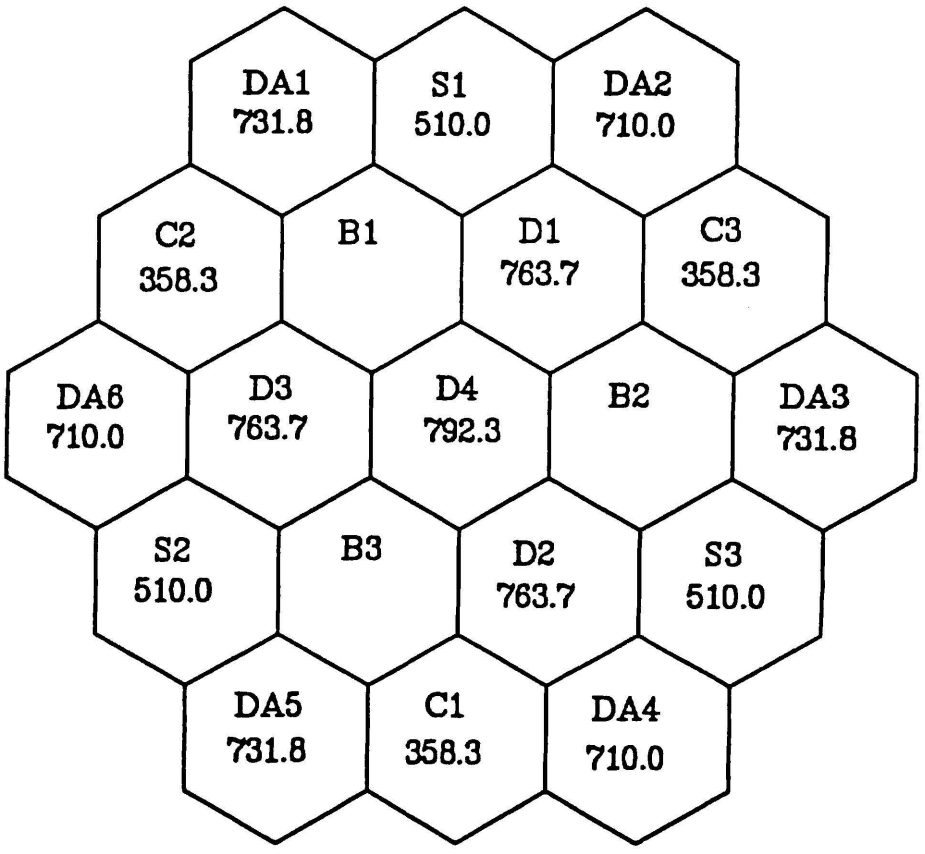

Figure 1
MCNP Calculated Channel Power Map for the Initial MAPLE-X10 Reactor Core Showing Channel Names and Power (kW)

The channel powers in Figure 1 total 10 MW, the full operating reactor power level. Powers have been averaged in groups of three channels for the middle and outer driver fuel channels, the channels with names beginning with 'D'. The three control rod channels and three shutoff channels are also averaged. These may be identified by the channel names beginning with 'C' and 'S' respectively. The averaging allows for the almost 120° rotational symmetry of the initial core. The three sites without power correspond to dummy aluminum and steel assemblies designed to limit the reactivity in the case of fresh fuel in the initial core.

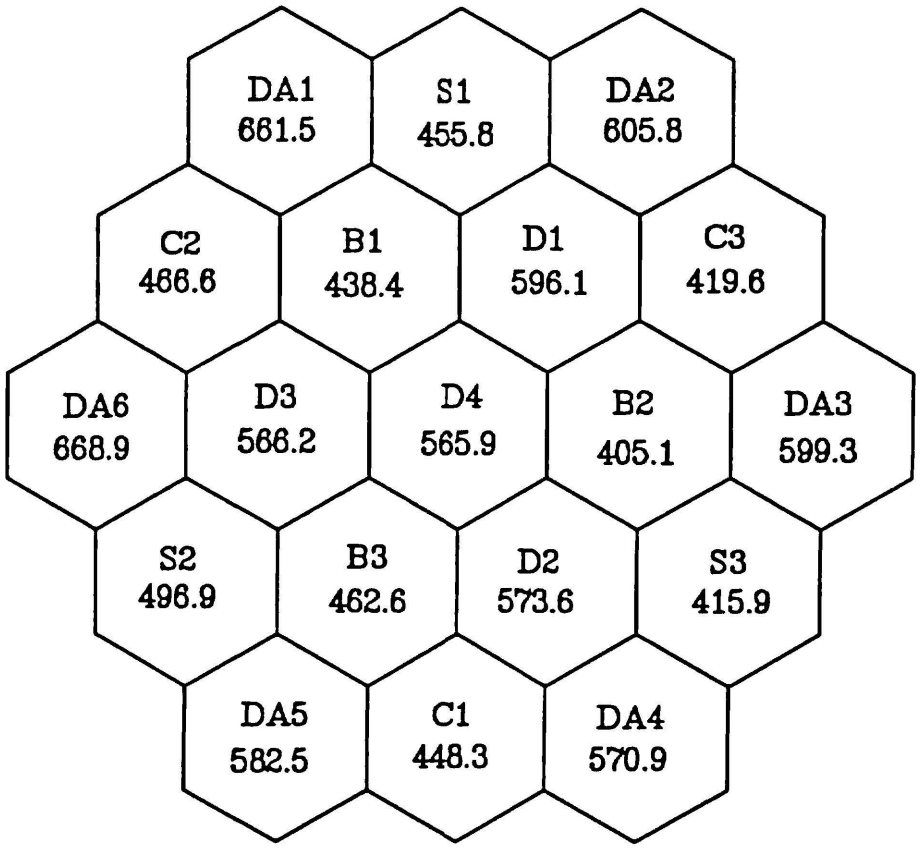

Figure 2
3DDT Calculated Channel Power Map for the Equilibrium
MAPLE-X10 Reactor Core Showing Channel Names and Power (kW)

Figure 2 shows the channel power map for the equilibrium core of the MAPLE-X10 Reactor. This core contains ten 36-element driver bundles and nine 18-element driver bundles. The inner 18-element bundles in channels B1, B2 and B3 replace the dummy assemblies in the initial core. Isotope production assemblies may be used to selectively replace some 18-element driver bundles.

The range of fuel burnups in Figure 2 result in different channel powers at all sites, and this is a consequence of the fuel shuffling scheme. MCNP may be used as well as 3DDT for MAPLE-X10 equilibrium core calculations. This was done for the equilibrium isotope production core calculation. The MCNP calculation required some additional modelling adjustments, using 3DDT, to properly account for the detailed burnup distribution. A limited number of burnup intervals were incorporated into the MCNP model. The predicted channel powers were scaled by the channel power ratios between two 3DDT model runs representing the approximated and detailed burnup distributions. The channel powers are used in CATHENA to determine the fuel heating in the thermalhydraulic model.

3.2 Axial Power Profiles

Axial power and neutron flux profiles were determined from 3DDT calculations. The axial power profiles are required to determine power peaking in the hottest pins. The axial flux profiles are used to determine weight factors in the reactivity feedback analysis. Weight factors are determined from the neutron flux, ϕ, using perturbation theory. The flux profiles will be discussed further in Section 4.2.2.

Once the powers in each channel have been determined, the normalized axial profile of the power determines the power in each axial node. The 60-cm length of fuel region is divided into eight axial nodes of equal length. The powers within these nodes are currently determined for channel equivalence classes, rather than individual channels. Generally the driver fuels are classified as central, middle, and outer drivers, and the remaining fuel as either control or shutoff channels or inner fuel channels B1, B2 and B3. Figure 3 shows an example of power profiles for the MAPLE-X10 Reactor in eight axial nodes for a typical equilibrium core. In this figure, the bottom of node 1 is at the bottom of the core.

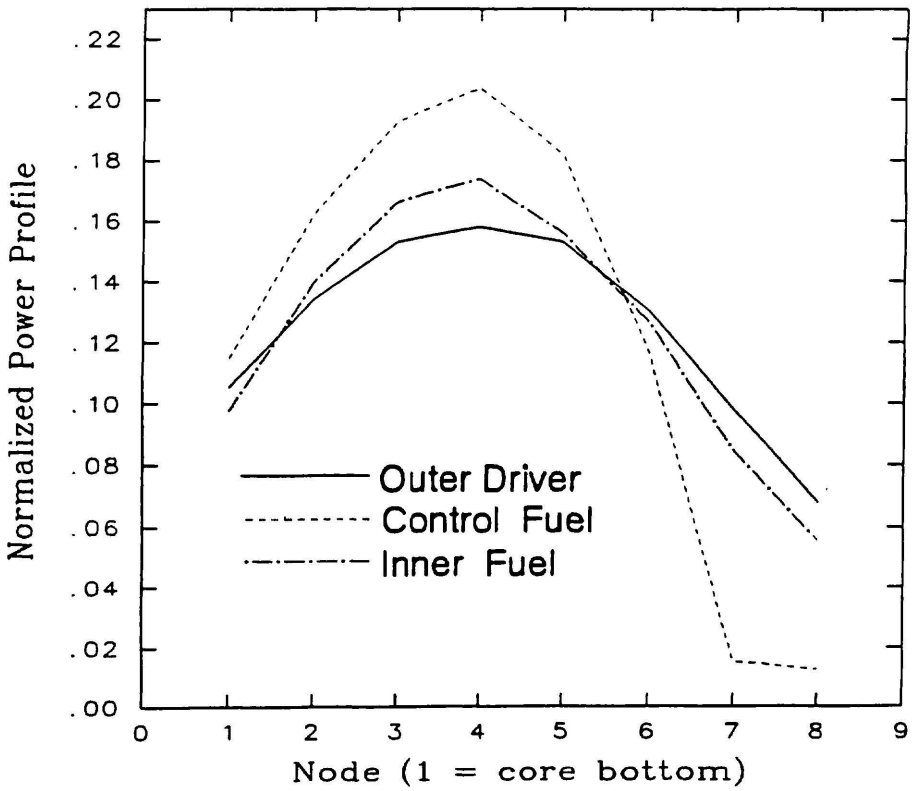

Figure 3
MAPLE-X10 Typical Equilibrium Core Power Profiles

The axial profile is required to predict the peak ratings in the hottest pins in conjunction with the pin-power distributions discussed in the next section. This information is used by CATHENA to determine the CHF margin in power peaks during analysis of postulated accident scenarios.

3.3 Pin Power Distributions

Detailed powers were obtained from MCNP for all pins in each bundle of the core. This data can be best summarized in a graph showing the distribution of powers in all 36-element fuel pins in the core and all 18-element fuel pins in the core for the case of the initial core. Figure 4 shows such a distribution of pin powers for 36-element pins and Figure 5 displays the distribution of pin powers for 18-element pins.

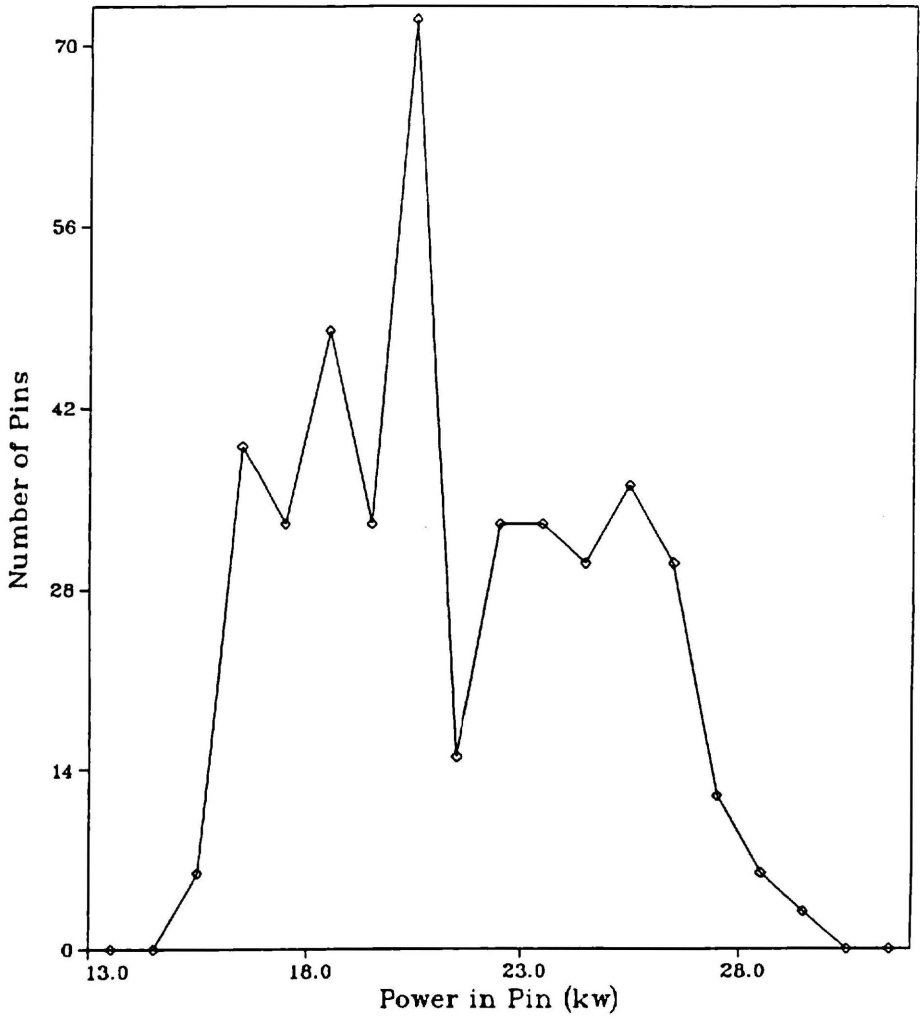

Figure 4
36-Element Driver Pin Power Distribution
in MAPLE-X10 Initial Core

There are a total of 360 driver pins in ten 36-element bundles and 108 pins in six 18-element bundles, corresponding to the areas under the graphs in Figures 4 and 5. This pin power distribution information permits the determination of the fraction of the pins in the core within a specified range of the CHF margin. If the operating core power level (10 MW) is scaled to the transient power during simulation of a postulated accident scenario using CATHENA, the pin powers may be appropriately scaled, assuming the point kinetics model is adequate. However, the axial power profiles need to be considered in the analyses to determine the actual peak, since the values shown in Figures 4 and 5 are the total powers in each pin in kW.

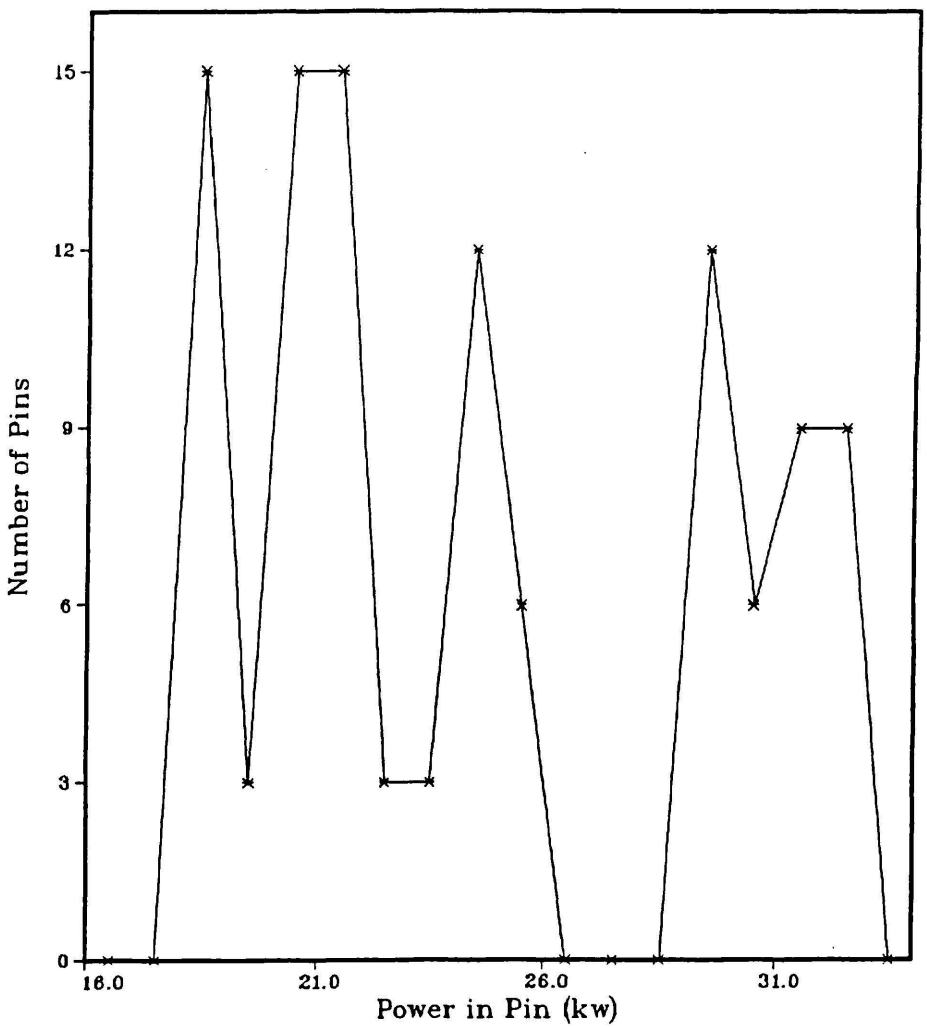

Figure 5
18-Element Fuel Pin Power Distribution
in MAPLE-X10 Initial Core

4.0 REACTIVITY FEEDBACK ANALYSIS

One of the most important physics contributions to the transient analysis is the reactivity feedback effect modelling. There are two factors involved in the reactivity feedback calculations: the reactivity coefficients and the statistical weighting scheme.

The change in reactivity, δk_{tot}, is determined from changes in parameters affecting reactivity in various regions of the core. This total reactivity change is obtained in CATHENA as the sum of individual contributions. These include fuel temperature, water temperature, water density (including void), ^{135}Xe concentration and external reactivity devices.

4.1 Reactivity Coefficients

To calculate the reactivity worth associated with a change in fuel and coolant temperatures and coolant density/voids in different regions of the core, it is necessary to evaluate reactivity coefficients.

The procedure used for evaluating these data is as follows. The WIMS-AECL input is produced by a batch editing process for all material models that change with the specified parameter. The parameter is set at a specified value, e.g., coolant temperature of 60°C or fuel temperature of 250°C, for all materials within the WIMS-AECL models subject to this change. WIMS-AECL is run for these models and the cross sections are combined to make a cross-section data file with the parameter change incorporated. These cross sections are converted into a form usable by MAPDDT, the utility code used to generate the formatted 3DDT input. Reactivity differences for the parameter change are determined using 3DDT as described in Section 2.1.

4.2 Statistical Weighting Scheme

Reactivity variations with parameter are not calculated for every possible distribution of fuel temperature, coolant temperature and coolant density. To predict reactivity feedback for a general configuration of parameters throughout the core nodes, statistical weights are used.

The reactivity coefficients are input to CATHENA in the form of tabulated data of quadratic curve-fits to the reactivity difference data. The reactivity coefficients are evaluated using 3DDT for uniform parameter changes throughout one fuel type at a time. The fuel types in MAPLE-X10 include 36-element driver fuel, and 18-element driver fuel. The latter is used in control, shutoff and sometimes in inner target sites. In the initial MAPLE-X10 core, dummy assemblies are used in place of 18-element bundles to limit reactivity. The target channels B1, B2, B3 may later contain 18-element drivers or isotope production targets.

4.2.1 Channel Class Weights. Reactivity change with parameter variation in the equivalent channel class is accomplished by the use of channel class weights. Channel class weights have been calculated on the basis of the square of total flux averaged over the axial nodes of the channel equivalence class. Comparison of total flux with thermal flux has shown that the total flux produces better channel class weights. Typical weights used in the CATHENA simulation of the MAPLE-X10 Reactor are summarized in Table 1. See Figures 1 and 2 for channel names and locations.

Table 1
Typical Channel Class Weight Factors

Equivalence Class	Fuel Type	Channel Names	Initial Core	Equilibrium Core
Central	Driver	D4	.1535	.1530
Inner	Driver	D1-D3	.3898	.3898
Outer	Driver	DA1-6	.4566	.4572
Control	Target	C1-C3	.4268	.2755
Shutoff	Target	S1-S3	.5732	.2967
Inner	Target	B1-B3	.0000	.4278

The inner target site for the initial core contains a dummy aluminum assembly and has zero weight factor in Table 1. This is because Table 1 displays weight factors for fuel channel contributions only. In fact, the coolant and moderator temperature reactivity effects for the dummy assemblies are important in the CATHENA kinetics analysis.

4.2.2 Axial Weights. Axial flux profiles are generated for equivalent channel classes in a manner similar to the power profiles shown in Figure 3. The normalized axial flux squared profiles are used to determine the weighting of the various axial nodes in the reactivity feedback analysis. Analysis of nonlocal void feedback effects has shown that thermal flux squared axial profiles produced the best results when compared with explicit calculations with the nonlocal void.

5.0 ADDITIONAL PHYSICS DATA

5.1 Neutron Kinetics Parameters

Certain parameters are needed to solve the point kinetics equations. These are provided from the physics input, and are discussed in this section.

The point kinetics model incorporated in CATHENA solves the point kinetics equations [8]. These equations are the full set of point kinetics equations for cases not including ^{135}Xe and are implemented in CATHENA as follows:

$$\frac{dn(t)}{dt} = \frac{\delta k(t) - \beta}{\Lambda} n(t) + \sum_{i=1}^{N} \lambda_i C_i(t)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i \, n(t)}{\Lambda} - \lambda_i C_i(t) \; ; \quad i = 1,\ldots,N$$

where

$n(t)$ = relative fission power at time t,

N = total number of delayed-neutron groups,
= 6 without photoneutron groups,
= 15 with photoneutron precursor groups,

$C_i(t)$ = i^{th} group delayed-neutron or photoneutron precursor concentration at time t,

β_i = i^{th} group delayed-neutron or photoneutron fraction,

λ_i = i^{th} group delayed-neutron or photoneutron decay constant,

β = $\Sigma\beta_i$ for i =1,...,N,

$\delta k(t)$ = $\delta k_{tot} = (k_{eff} - 1)/k_{eff}$, excess reactivity, and

Λ = l^*/k_{eff} = prompt neutron generation time, where

l^* = prompt neutron lifetime.

The kinetics parameters currently used in MAPLE-X10 are summarized in Table 2. These have been generated for the initial core, and are used in TANK and CATHENA. In addition, the prompt neutron generation time was calculated using TANK to be

$$\Lambda = 7.0 \times 10^{-5} \text{ s.}$$

Table 2
Delayed Neutron Fractions
And Decay Constants

Delayed Neutron Groups i	Fraction β_i	Decay Constant λ_i (s^{-1})
1	2.76×10^{-4}	1.33×10^{-2}
2	1.40×10^{-3}	3.25×10^{-2}
3	1.20×10^{-3}	1.22×10^{-1}
4	2.54×10^{-3}	3.17×10^{-1}
5	1.30×10^{-3}	9.85×10^{-1}
6	6.57×10^{-4}	2.96

5.2 ^{135}Xe Effects

The ^{135}Xe reactivity feedback effect is incorporated into the point kinetics equations by the addition of two additional equations. These two equations govern the concentrations of ^{135}Xe and ^{135}I in the reactor core. The calculated ^{135}Xe concentration is used to determine an additional reactivity feedback term.

$$\frac{dC_{x\bullet}(t)}{dt} = -\lambda_{x\bullet} C_{x\bullet}(t) + \lambda_I C_I(t) + \gamma_{x\bullet} c_o n(t) - \alpha_{x\bullet} c_o n(t) C_{x\bullet}(t)$$

$$\frac{dC_I(t)}{dt} = -\lambda_I C_I(t) + \gamma_I c_o n(t)$$

where $C_{x\bullet}$ = the concentration of ^{135}Xe at time t,

C_I = the concentration of ^{135}I at time t,

$\lambda_{x\bullet}$ = the decay constant of ^{135}Xe,

λ_I = the decay constant of ^{135}I,

$\gamma_{x\bullet}$ = the fission yield of ^{135}Xe,

γ_I = the fission yield of ^{135}I,

$\alpha_{x\bullet}$ = a constant to account for the ^{135}Xe depletion rate due to neutron absorption. It is proportional to the microscopic capture cross section of ^{135}Xe divided by the macroscopic total fission cross section, and

c_0 = a normalization factor determined by the units in which the concentrations $C_{x\bullet}$ and C_I are specified. The product of $c_0 n(t)$ is proportional to the number of fissions per second.

The decay constants and fission yield values used in MAPLE-X10 analysis are given below:

Decay Constant		Fission Yield	
$\lambda_{x\bullet}$	$= 2.1182 \times 10^{-5}\ s^{-1}$	$\gamma_{x\bullet}$	$= 2.40 \times 10^{-3}$
λ_i	$= 2.9129 \times 10^{-5}\ s^{-1}$	γ_i	$= 6.30 \times 10^{-2}$

These fission yields are based upon the initial MAPLE-X10 core where there are 99.31% fissions in ^{235}U and 0.69% of fissions in ^{238}U. The initial core concentration ratio, $r_\bullet$, is 4.52 and the ^{135}Xe reactivity worth, $\delta k_{x\bullet,r}$ is 35.1 mk.

The constant c_o is related to the initial starting power P_o in watts at time zero in the simulation by

$$c_o = (\lambda_I / \gamma_I) \times 10^{-7} r_\bullet P_o \ .$$

5.3 Power Deposition

To determine the heat deposition in different parts of the core, MCNP was used with a full-core model of MAPLE-X10. Both initial core and equilibrium isotope production cores were analyzed. Gamma transport as well as neutron transport was considered.

A summary of the heat deposition results is given in Table 3.

Table 3
Power Depositions
10 MW = Total Thermal Power in the Core

	Initial Core Fresh Fuel	Equilibrium Isotope Production Core
All Fuel	9.5944	9.5388
Flow tubes	0.1268	0.1254
Coolant	0.1769	0.2012
Interstitial Water	0.1019	0.1345
TOTAL in core	10.000	10.000
D_2O Tank	0.3204	0.3646
Pool Water	0.0166	0.0199
Escaping Energy	0.0237	0.0261
TOTAL cumulative	10.361	10.411

5.4 Decay Heat Curves

Decay heat power is released in the fuel according to a complex function of the previous fission power history. CATHENA does not calculate decay heat power time-dependence explicitly during simulations, but instead uses precalculated curves based on shutdown from assumed power histories.

The decay heat power time-dependence curves used in CATHENA for MAPLE-X10 were calculated from TANK analyses using the ANS 1978 Standard [9] for decay heat power from fission products. The values currently used in MAPLE-X10 analyses are directly stored as tables in CATHENA. CATHENA also allows for a user to specify the decay curve through data in the input file.

The decay heat power curves are summarized in Figure 6. The MAPLE-X10 Reactor initial core is assumed to operate at 10 MW power for durations of 1.0×10^4 s, 1.0×10^5 s and 1.0×10^7 s prior to shutdown, and the decay heat power for each of the three cases is plotted in Figure 6. Only ^{235}U and ^{238}U fissions were considered for these curves. The neglect of ^{239}Pu fissions in the long fuel irradiation case slightly overestimates the decay heat power.

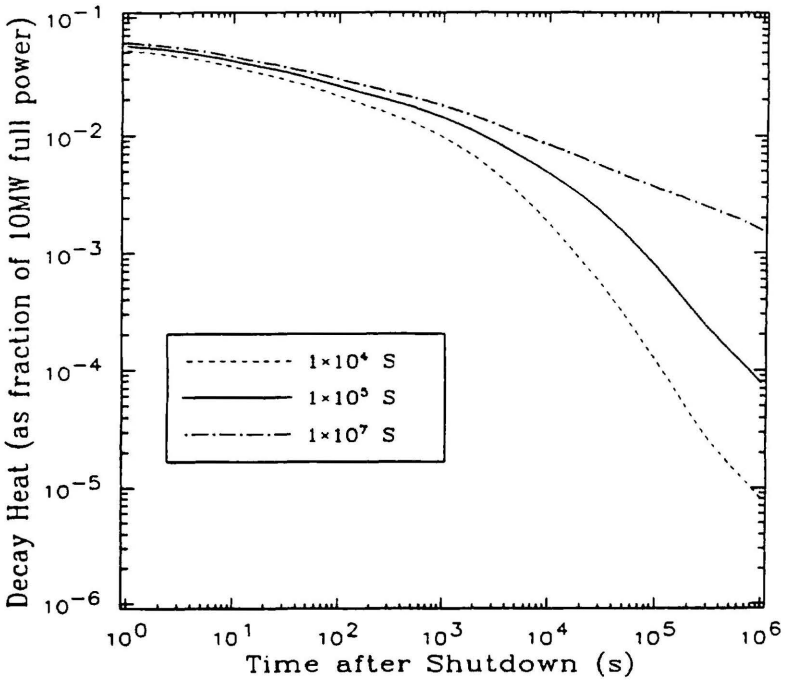

Figure 6
MAPLE-X10 Decay Heat Curves After Various Operational Periods

5.5 External Reactivity Devices

The reactivity feedback equation includes a term for an external reactivity contribution, δk_{ex}. The major contributors to this are the control absorbers and shutdown absorbers. The contributions of the three control absorbers moving together have been predicted using WIMS-AECL/3DDT, and are plotted in Figure 7. This provides the reactivity difference as a function of the control rod position. If a transient scenario involves control rod motion, these curves are used to predict the effect upon δk_{ex}. The control rods can move a total distance of 700 mm.

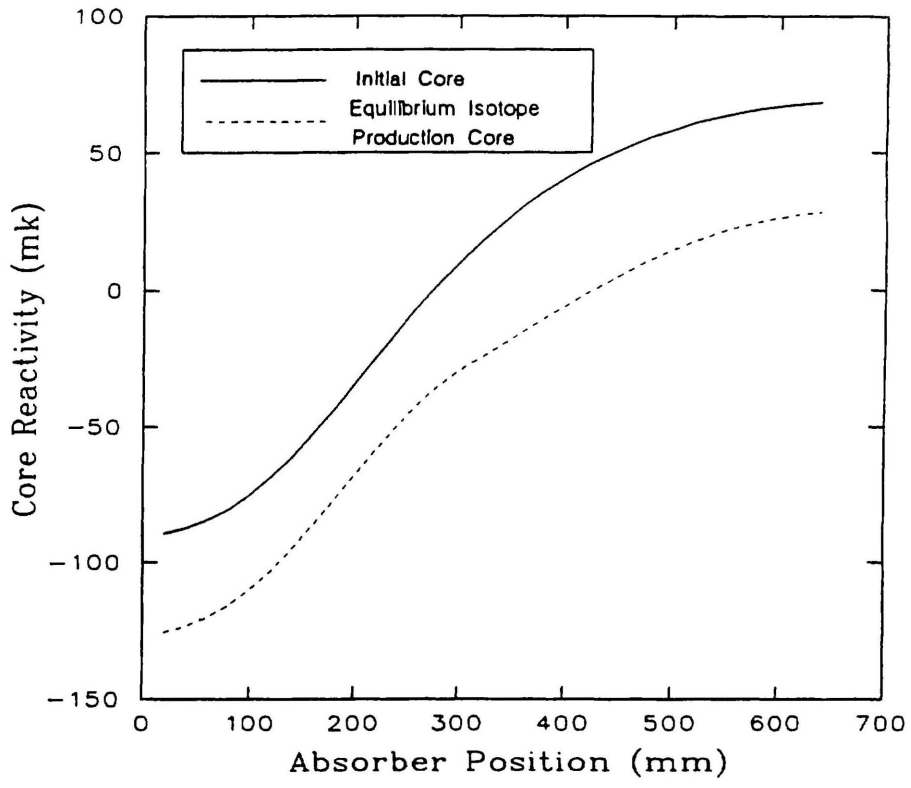

Figure 7
Reactivity Calibration Curves for MAPLE-X10 Control Rods

The other major contributor to external reactivity is the shutdown absorber worth and the time required for this reactivity change to take effect. A shutdown reactivity curve, as a function of time (see Figure 8), was calculated using TANK. The tabulated values of time in s and reactivity in mk for the simultaneous dropping of three hafnium shrouds over the shutdown assemblies for the initial MAPLE-X10 core is plotted in Figure 8. The shutdown reactivity data were supplied in a table to CATHENA for MAPLE-X10 simulations. The shutdown absorbers (hafnium shrouds) drop at an arbitrary 0.002 s, and are completely inserted in 0.9 s. There is no control rod movement assumed during this shutdown.

In simulations where shutdown is initiated by a trip, this shutdown reactivity curve can show the effectiveness of the shutdown system in preventing further power rise during a transient.

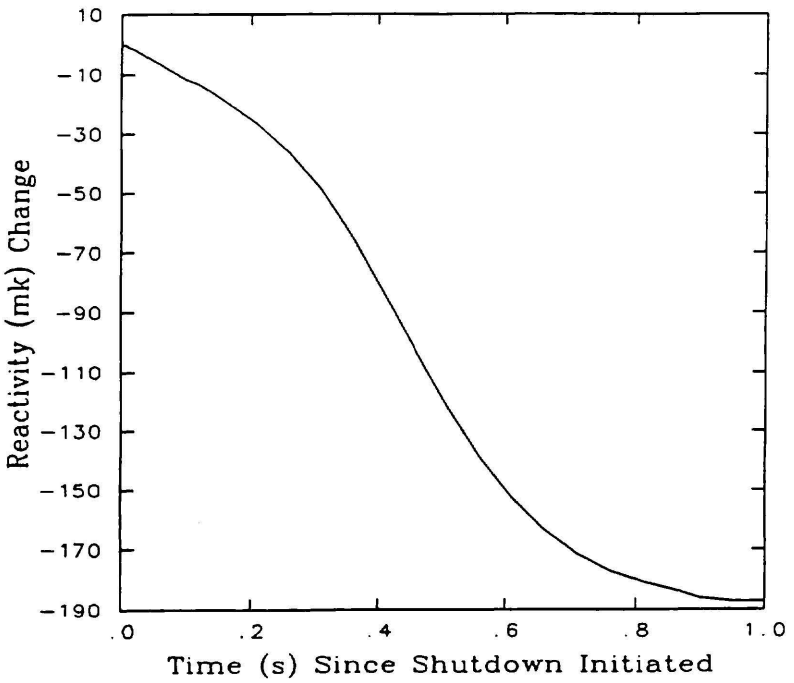

Figure 8
Reactivity Drop in MAPLE-X10 From Insertion
of Three Shutdown Absorbers

6.0 SAMPLE CATHENA SIMULATION

The CATHENA code employs a detailed thermalhydraulic model of the core, including two-phase flow. This code provides a means to predict fuel centre and cladding temperatures, overall reactivity and reactivity feedback from temperature and void, core powers, and flow and pump performance during the simulated transients as functions of time. Various postulated accident scenarios have been analyzed for MAPLE-X10 with CATHENA, including loss-of-regulation and loss-of-core-cooling. The correct modelling of the reactivity feedback effects is a very important physics contribution to the transient analysis. To see the effects of reactivity feedback on the results of a transient analysis, we present the results of a simulation of a postulated accident scenario for the MAPLE-X10 Reactor performed using CATHENA. The best estimate reactivity coefficients are used. This means that no error bounds have been applied to the coefficients in order to increase predicted reactor power during a transient as has been done [10] with the worst-case reactivity coefficients.

In this scenario, the reactor was assumed to be operating in the cold startup state at a low power of 2 kW, with the entire core at room temperature conditions and 290 kg/s primary flow. The control rods were assumed to move at time zero and insert 2 mk as a step reactivity insertion in a zero time interval. It was assumed they froze in this position and did not drop into the core. As well, no shutoff rods were assumed to drop into place. The equilibrium isotope production core was analyzed.

The initial coolant inlet temperature was 20°C. The heat exchanger was modelled with actual surface area and wall mass, and primary and secondary side flows were modelled to calculate the heat removal rate realistically. The system control model was also used to control the primary coolant temperature at 20°C by controlling the secondary side flow.

The results of the simulation are shown in Figures 9 through 12. The reactivity contributions of the control rod movements are shown in Figure 9 along with the negative reactivity feedback from increases in fuel temperature and coolant temperature. These effects each approach -1 mk and serve to cancel the 2 mk added by the control rods, bringing the total reactivity to zero.

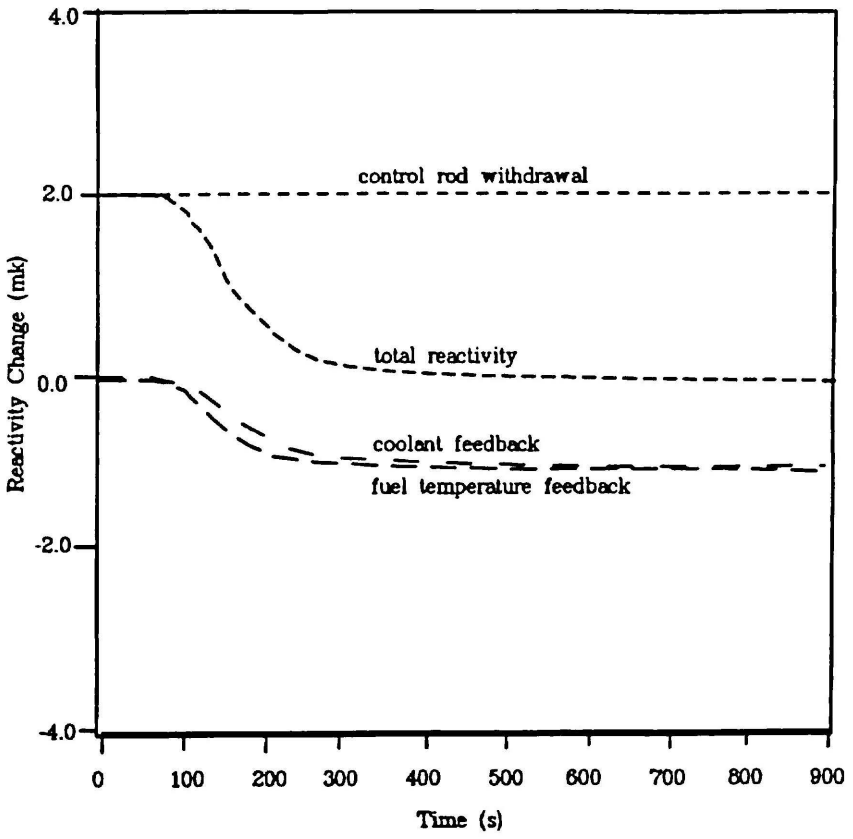

Figure 9
Reactivity Feedback for Loss of Regulation at 2 kW
Using Best Estimate Reactivity Coefficients

Figure 10 shows the total core power. At about 100 seconds after the start of the transient, the power rises to a level that becomes visible on the megawatt scale. At about 300 seconds, the negative reactivity feedback effects of coolant and fuel temperature increases stabilize the power at about 17 MW. The power remains stable at this level during the 900 seconds covered in the simulation. The power stays at this level because the total reactivity in Figure 9 has stabilized to zero.

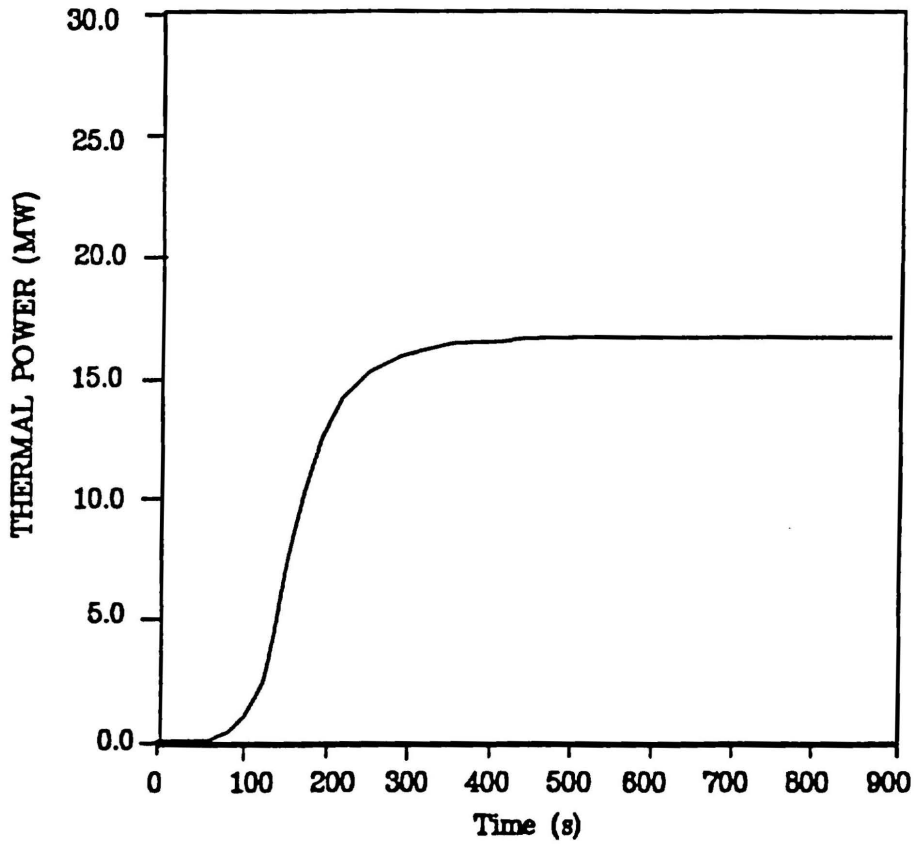

Figure 10
Core Power for Loss of Regulation at 2 kW
Using Best Estimate Reactivity Coefficients

The predicted fuel centreline temperatures are shown in Figures 11 and 12. Here the centreline fuel temperatures of the hottest pins in the core are shown at eight axial positions along the 60-cm fuel length. The first four are plotted in Figure 11 and the last four in Figure 12. The distance from the fuel bottom to the fuel region whose temperature is plotted is indicated on each graph. The melting point for the U_3SiAl fuel is over 640°C.

The graphs show that the highest fuel temperature occurs in axial node position 4, as would be anticipated from Figure 3. This temperature stabilizes well within the safety margin for this scenario.

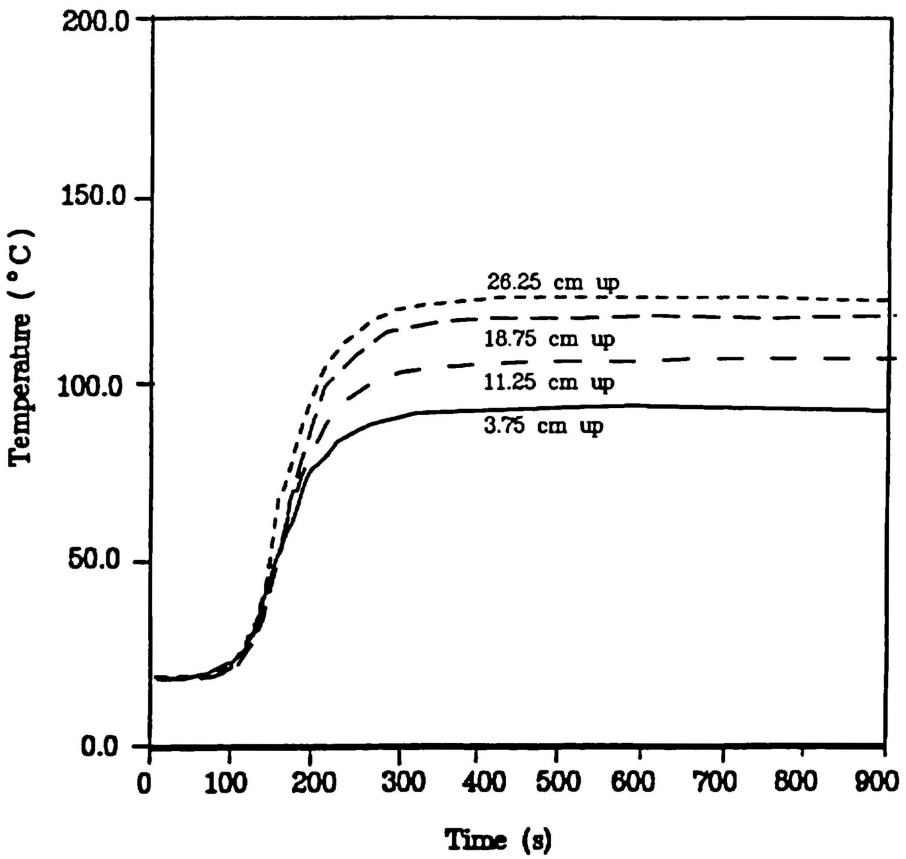

Figure 11
Centreline Fuel Temperature for Loss of Regulation at 2 kW in Lower Half of Core Using Best Estimate Reactivity Coefficients

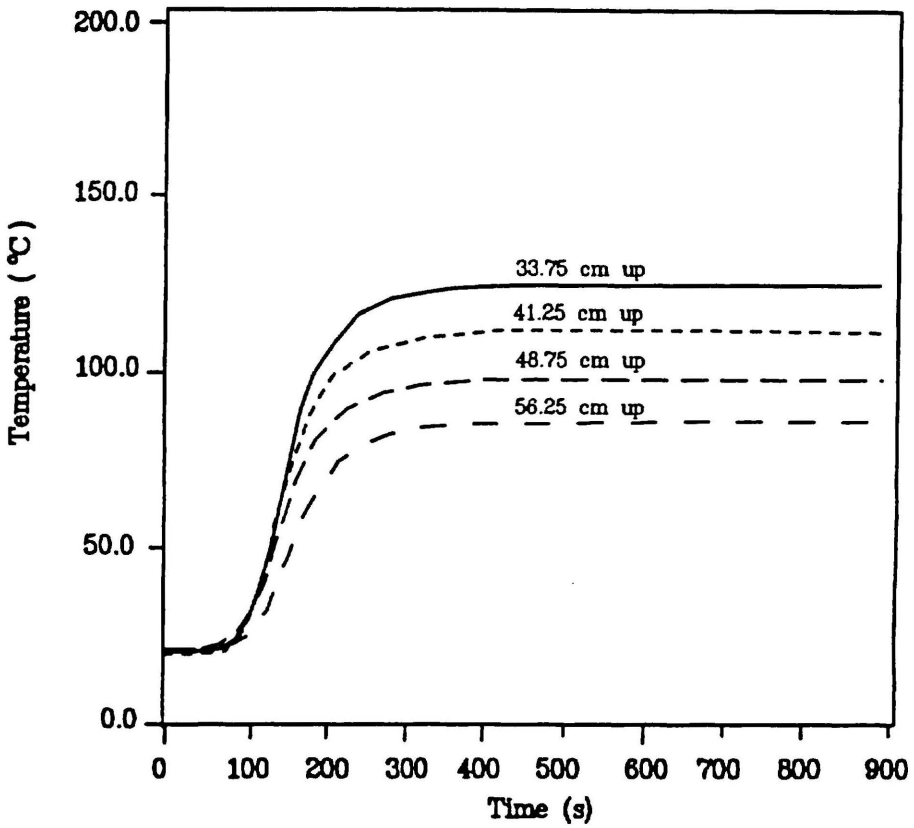

Figure 12
Centreline Fuel Temperature for Loss of Regulation at 2 kW in Upper Half of Core Using Best Estimate Reactivity Coefficients

7.0 ACCURACY AND FURTHER ANALYSES

We have examined the various sources of physics input data required for transient analyses of MAPLE-X10 using CATHENA. A wide variety of physics analyses are required to perform these simulations. The safety analyses depend heavily upon transient analyses, and the accuracy of the results of transient analyses depends heavily upon the physics input provided. Consequently, this review provides a means for assessing the factors contributing to the analyses, and a means to determine which factors should be examined further for the accuracy and sensitivity of the results.

Additional analyses have been performed [6,10] as a result of consideration of the factors in this study. These include

1. reactivity coefficient accuracy and sensitivity analysis,
2. comparison of WIMS-AECL and 3DDT modelling methods with alternate methods,

3. further code benchmark comparisons with MCNP,
4. analysis of factors determining channel and axial weights, and
5. analysis of local axial void effects on reactivity feedback as predicted by statistical weighting schemes.

8.0 SUMMARY

We have described the various diverse areas of reactor physics contributions required for transient analysis simulations. These include axial and channel powers, pin powers, reactivity feedback effects, neutron kinetics parameters, power deposition, decay heat power and external reactivity devices.

With this physics data provided, we have illustrated a typical example of a transient analysis simulation using CATHENA for a loss-of-regulation accident. The CATHENA code provides predicted reactivity, core power and fuel centreline temperatures in the hottest pins, along with other thermalhydraulics predictions as a function of time during the simulation. These results permit safety assessments of the MAPLE-X10 Reactor design to be made.

9.0 ACKNOWLEDGEMENTS

The help of W. Heeds [11] is gratefully acknowledged in the preparation of reactivity coefficient data for MAPLE-X10.

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