

THE STABILITY ANALYSIS OF LAPUR6 FOR CHINSHAN BWR NUCLEAR POWER PLANT

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Abstract

Chinshan Nuclear Power Plant (NPP) is the first NPP in Taiwan which is a BWR/4 plant. The original rated power for each unit was 1775 MWt. After the project of measurement uncertainty recovery (MUR) for Chinshan NPP, the operating power is 1805 MWt now. The Chinshan NPP Unit 2 cycle 23 stability analyses were performed by the LAPUR6 stability analysis methodology. Comparing the LAPUR6 stability analysis results and vendor's results, they are similar.

Introduction

Unstable power/flow oscillation of a nuclear power reactor core is one of the main reasons which cause core damage. In 1988, LaSalle unit2 experienced core instability incident, and drew worldwide attention [1]. Such kinds of stability issue are closely related to operational safety of boiling water nuclear reactors. To prevent core instability events from happening, stability analysis needs to be performed at each core reloads design. In each BWR reload core design, to assure safety operation of the nuclear reactor, the fuel vendor is required to provide instability boundaries on NPP power/flow map. In order to establish a capability to carry out independent verification of the vendor's results, Taiwan Power Company (TPC), Institute of Nuclear Energy Research (INER), and National Tsing Hua University (NTHU) are working together to develop a suitable stability analysis methodology for such purposes.

In our current research, two major computer codes have been adopted, the frequency domain stability analysis code - LAPUR6 and the 3-D neutronic code - SIMULATE-3. A set of analysis procedures plus certain interface programs are organized together. The stability analyses results of LAPUR methodology are compared with the vendor's STAIF prediction results. STAIF is also a frequency domain code and the accuracy of STAIF-calculated decay ratio is ± 0.15 for the global decay ratio (± 0.20 for the regional decay ratio) [2].

Chinshan NPP is the first NPP in Taiwan. It is a BWR/4 plant and the original rated power for each unit is 1775 MWt. The Unit 2 of Chinshan NPP started MURPU (Measurement Uncertainty Recovery Power Uprate) from April 6, 2008 and the Unit 1 started MURPU from November 8, 2008. The operating power is 101.7% of the original designed rated power, which is 1805 MWt now. In this research, the cycle 23 stability analysis of Chinshan NPP Unit 2 was performed by the LAPUR6 stability analysis methodology.

1. LAPUR6 Stability Analysis Methodology

LAPUR6, based on frequency domain approach, is a computer code that analyzes core stability and calculates core's decay ratio (the accuracy of LAPUR-calculated decay ratio is roughly ± 0.20) [2]. Basically, LAPUR6 is divided into two separate programs, including LAPURX and LAPURW. LAPURX solves the steady state governing equations of coolant and fuels. LAPURW is programmed to handle the dynamic equations of coolant, fuels and core neutronics in the frequency domain. Figure 1 depicted the analytic procedures of LAPUR6 methodology in this study. In this methodology, LAPUR6, SIMULATE-3, PAPU, EXAVERA, and DRASM are used to study core stability [3]-[6]. First, SIMULATE-3 analyzes the core detailed hydraulic and neutronic configuration of the different state points and perform perturbation calculations in LAPUR6 stability analysis methodology. Second, SIMULATE-3 output files and PAPU are used to obtain Doppler and reactivity density coefficients. Third, EXAVERA calculates channel grouping, flow distribution, axial power profile, power fraction, and contraction coefficients from SIMULATE-3 output files. Fourth, these above data and plus other information (for example, recirculation loop gain and time constant) to generate LAPUR6 input files (LAPURX.DAT and LAPURW.DAT). Fifth, by LAPUR6 performed, two LAPUR6 output files (LAPURX.OUT and LAPURW.OUT) can be obtained. Finally, DRASM checks the consistency of LAPUR6 and SIMULATE-3 in density reactivity coefficient, pressure drop, and flow distribution. If the above parameters of LAPUR6 are not consistent with the parameters of SIMULATE-3, new density reactivity coefficient, pressure drop, and flow distribution are assumed and new iterations are repeated. If the iteration converges, the calculation stops.

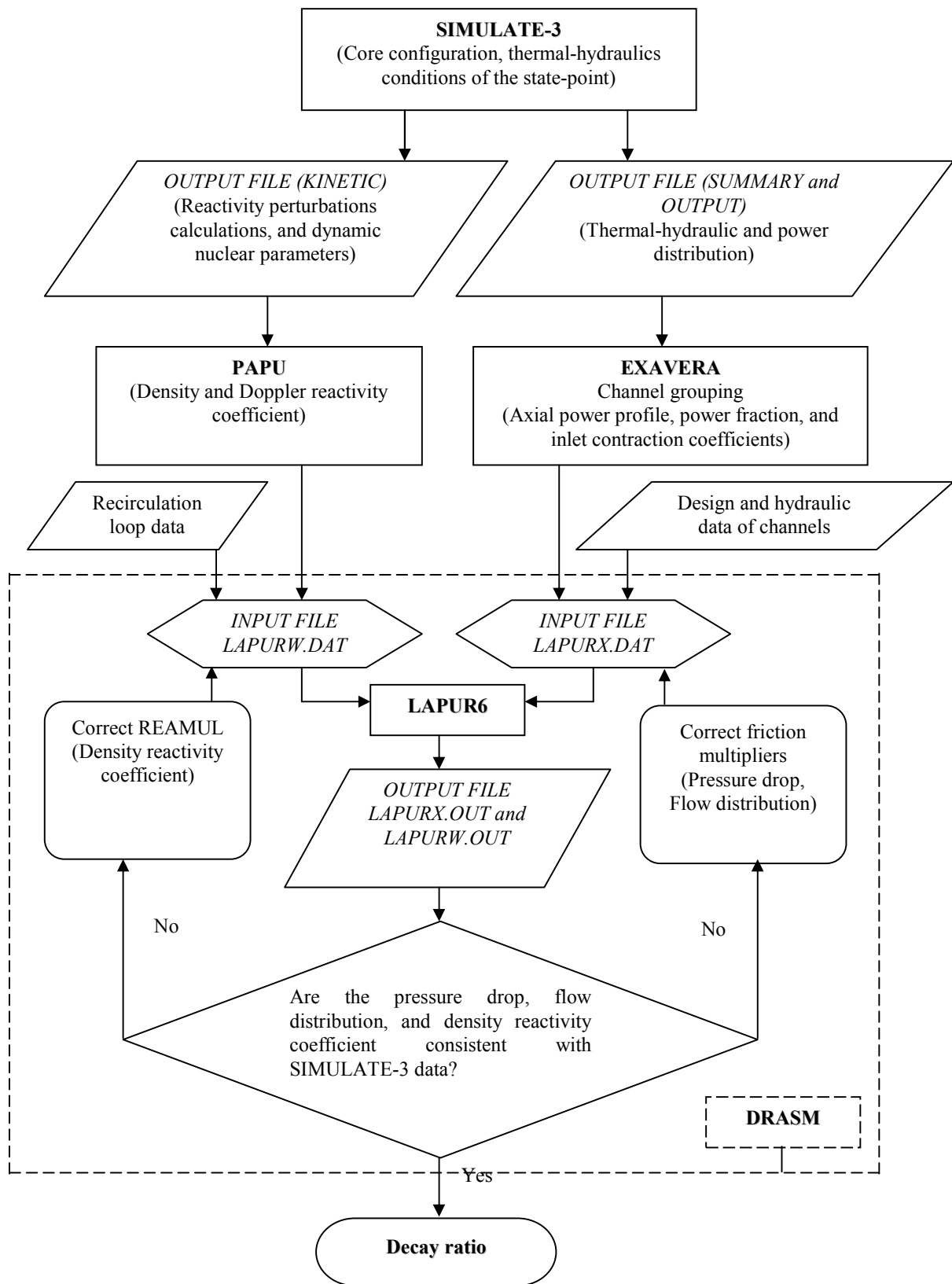


Figure 1 LAPUR6 stability analysis methodology.

2. Chinshan NPP Unit 2 Cycle 23 Stability Results

In Chinshan NPP Unit 2 Cycle 23 reload design, there was only one fuel type - ATRIUMTM-10⁺ in the core, and some operating conditions are shown in Table 1. In this study, all fuel assemblies are divided into twelve regions which are shown in Figure 2. The sum of relative power in each region is not to exceed 20% total power. This requirement guarantees a good description of the radial power shape, especially for the high power channels.

In the power/flow map (shown in Figure 3), there are ten operating points corresponding to two kinds of decay ratio values (0.90 and 0.85), which are calculated by vendor's STAIF programs. In the decay ratio 0.90 boundary, the operation points (%power/%flow) are 49.8/36.6, 53.0/38.3, 58.9/41.0, 66.2/44.0, and 72.9/46.5. In the decay ratio 0.85 boundary, the operation points (%power/%flow) are 48.9/36.7, 52.0/38.3, 57.8/41.0, 64.4/44.0, and 74.6/48.4. Because these data belong to the vendor, the detailed decay ratios of the above points do not share in this paper. So the results of LAPUR6 only compare with the boundaries decay ratios which are 0.85 and 0.90. Besides, the LAPUR6 analyses are performed from BOC to EOC in all points. Table 2 and 3 show the analysis results of LAPUR6 methodology and these results are the maximum decay ratio in each point analysis. By comparing the results of LAPUR6 and STAIF, the maximum difference in decay ratio was 0.19 (In point "53.0/38.3", the decay ratio is 0.71, $0.90-0.71=0.19$) between these two approaches. This difference may be caused by the difference of some input parameters and the neutronic model (LAPUR6 is a point kinetic model; STAIF is a one-dimensional neutron kinetic model). These parameters are different value in LAPUR6 and STAIF. In the comparison of LAPUR6 and STAIF parameters, fuel gap conductance, density reactivity coefficient, and delayed-neutron fraction have larger differences. Therefore, the sensitivity studies of these parameters are performed. The analysis results of the sensitivity studies are described in the next section.

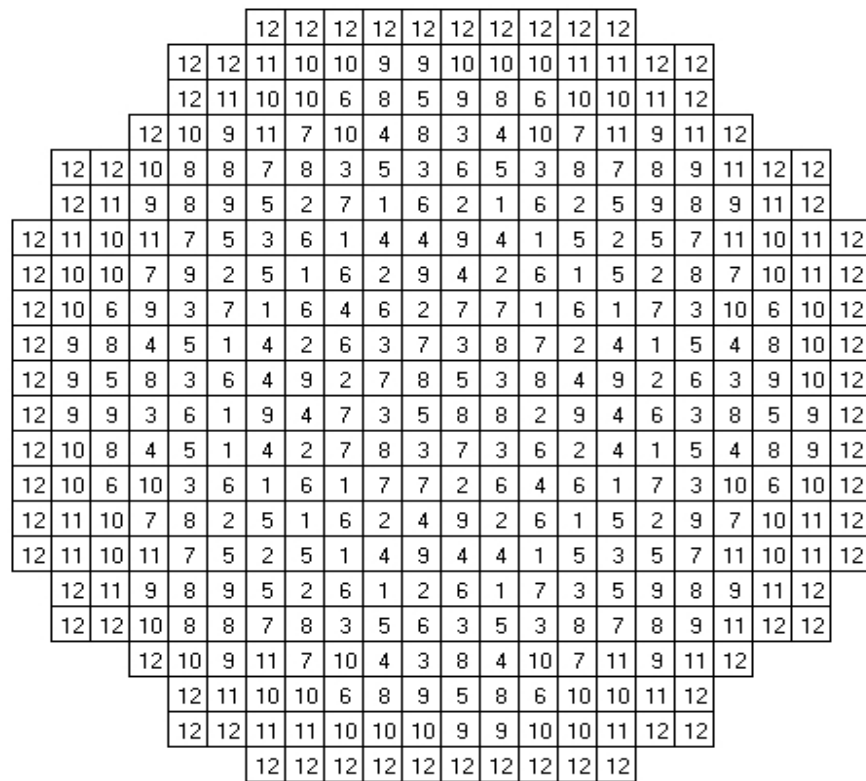


Figure 2 Divided regions of Chinshan NPP Unit 2 Cycle 23 for LAPUR6 stability analysis.

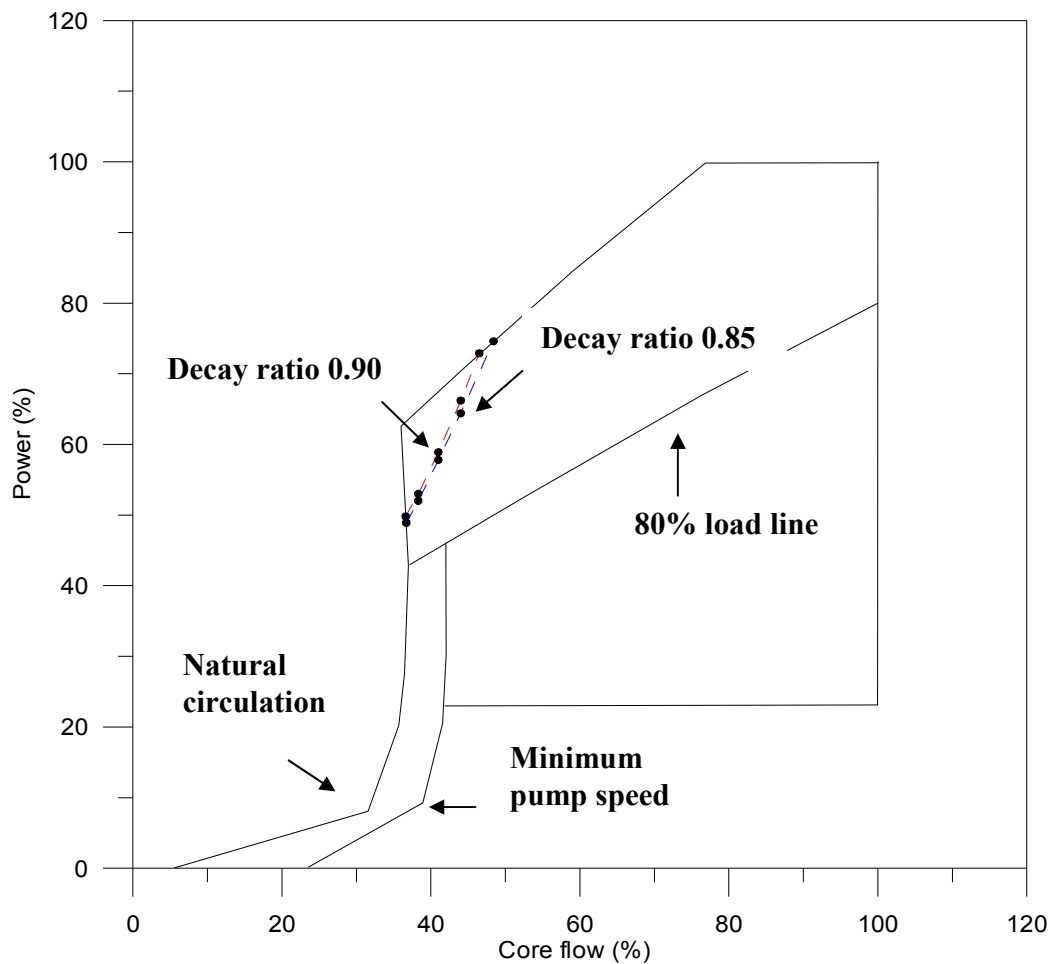


Figure 3 The power/flow map of Chinshan NPP Unit 2 Cycle 23.

Table 1 Operating conditions of core.

Core data	
Number of fuel assemblies	408
Rated thermal power, MWt	1805
Rated core flow, Mlbm/hr	53
Rated core inlet subcooling, Btu/lbm	20.6
Moderator temperature, °F	546

Table 2 LAPUR stability results for power/flow map instability boundary (decay ratio 0.90).

Power(%) / flow(%)	Decay ratio
49.8/36.6	0.85
53.0/38.3	0.71
58.9/41.0	0.80
66.2/44.0	0.77
72.9/46.5	0.81

Table 3 LAPUR stability results for power/flow map instability boundary (decay ratio 0.85).

Power(%) / flow(%)	Decay ratio
48.9/36.7	0.84
52.0/38.3	0.69
57.8/41.0	0.72
64.4/44.0	0.71
74.6/48.4	0.71

3. Sensitivity Studies

Sensitivity studies are performed in all points. However, in this paper, only one point is chosen for the following discussions. This point is 48.9/36.7 (base case) and the parameters data of this point list in Table 4.

3.1 Fuel Gap Conductance

Table 5 shows the decay ratio results for the sensitivity analysis of fuel gap conductance. The variation of fuel gap conductance is $\pm 40\%$. In this cycle stability analysis, for all points, the values of fuel gap conductance roughly include in this variation range. A variation of $\pm 40\%$ fuel gap conductance resulted in the decay ratio that changed from 0.90 to 0.67. As the fuel gap conductance increases from 0% to +40%, the decay ratio increases from 0.84 to 0.90. The increase of fuel gap conductance causes the more heat released to core which makes the core more unstable. On the other hand, as the fuel gap conductance decreases from 0% to -40%, the decay ratio decreases from 0.84 to 0.67. From above results, it indicates that this parameter is sensitive. Additionally, in reference 7, it describes that the increase in fuel gap conductance raises the reactivity feedback gain thus making the core more unstable. Hence, this is the same with our results.

3.2 Density Reactivity Coefficient

Table 6 shows the results for the sensitivity analysis of density reactivity coefficient. A variation range of density reactivity coefficient is $\pm 20\%$. The values in the variation of density reactivity coefficient may be used in this cycle stability analysis. As the density reactivity coefficient decreases from +20% to -20%, the decay ratio decreases from 0.99 to 0.68. It is clearly seen that the core is more unstable with a larger density reactivity coefficient from above data. The increase of density reactivity coefficient causes the increase of reactivity feedback gain, so that the core is more unstable. Additionally, by the comparison of results of fuel gap conductance and density reactivity coefficient, it indicates that this parameter is more sensitivity than fuel gap conductance.

3.3 Delayed-Neutron Fraction

The sensitivity analysis result of delayed-neutron fraction (six groups) is shown in Table 7 and the variation range of delayed-neutron fraction is $\pm 20\%$. In this variation range, the values of delayed-neutron fraction roughly include in this cycle stability analysis. As the delayed-neutron fraction increases 20%, the decay ratio decreases from 0.84 to 0.71. As the delayed-neutron fraction decreases 20%, the decay ratio increases from 0.84 to 1.02. It indicates that the delayed-neutron fraction is a sensitive parameter for decay ratio from above results. Besides, it also indicates that this parameter is more sensitivity than fuel gap conductance.

3.4 Axial variable areas

There is new function implanted in LAPUR6. That is the capability of modeling channels with variable areas. This new function can simulate the partial-length rods of the new fuel designs. Table 8 shows the stability analysis results of full-length and partial-length fuel assemblies. It shows their single-phase pressure drop are nearly the same, but the two-phase pressure drop of full-length rods is larger than partial-length rods. In Figure 4, in the top of fuel assemblies, it shows that there is larger flow area (flow area A) in partial-length rods fuel assemblies than in full-length rods fuel assemblies. So it makes the two-phase pressure drop of partial-length rods fuel assemblies lower than full-length rods and reduces decay ratio.

4. Conclusion

In this research, the LAPUR6 stability analysis methodology has established for Chinshan NPP operational stability assessments. By the comparisons of LAPUR6 and vendor predictions in Chinshan NPP Unit2 Cycle 23 reload design, it shows that the maximum difference in decay ratio is 0.19. Besides, the sensitivity studies of some parameters are performed. From the sensitivity studies results, it indicates that the fuel gap conductance, density reactivity coefficient, and delayed-neutron fraction are sensitive parameters for LAPUR6 stability analysis.

5. References

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6. Acknowledgements

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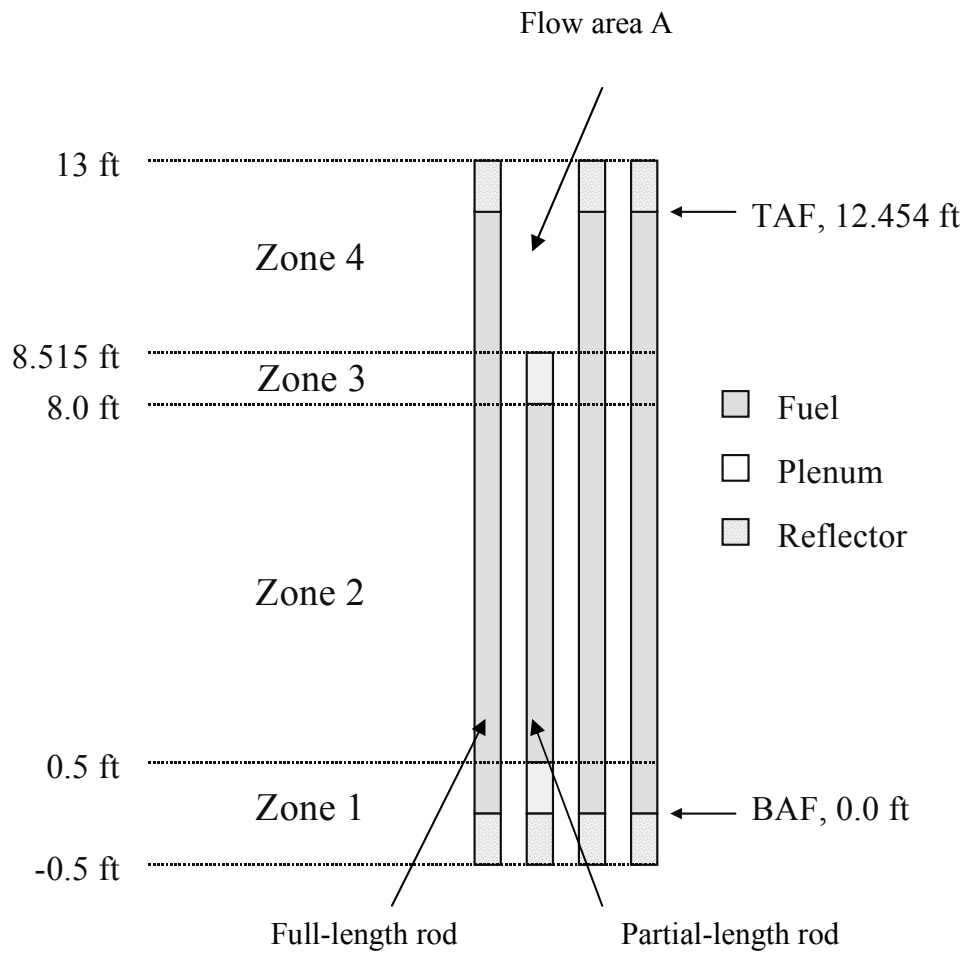


Figure 4 Axial fuel composition map.

Table 4 The parameters data of base case (48.9/36.7).

	Value
Gap conductance, (cal/cm² · sec · °C)	0.1268
Density reactivity coefficient (DRC), (%△K/K)/(gr/cm³)	14.261
Delayed-neutron fraction	5.682E-03

Table 5 The sensitivity studies of fuel gap conductance.

	Gap conductance, (cal/cm² · sec · °C)	Decay ratio
Base	0.1268	0.84
+20%	0.1522	0.88
+40%	0.1775	0.90
-20%	0.1014	0.77
-40%	0.0761	0.67

Table 6 The sensitivity studies of density reactivity coefficient.

	Density reactivity coefficient (DRC), (% Δ K/K)/(gr/cm ³)	Decay ratio
Base	14.261	0.84
+20%	17.113	0.99
-20%	11.409	0.68

Table 7 The sensitivity studies of delayed-neutron fraction.

	Delayed-neutron fraction	Decay ratio
Base	5.682E-03	0.84
+20%	6.818E-03	0.71
-20%	4.545E-03	1.02

Table 8 The sensitivity studies of axial variable areas.

	Two-phase pressure drop (kg/cm ²)	Single-phase pressure drop (kg/cm ²)	Two-phase pressure drop/ Single-phase pressure drop Ratio	Decay Ratio
Full-length rods fuel assemblies	0.332	0.042	7.90	0.84
Partial-length rods fuel assemblies	0.306	0.041	7.46	0.65