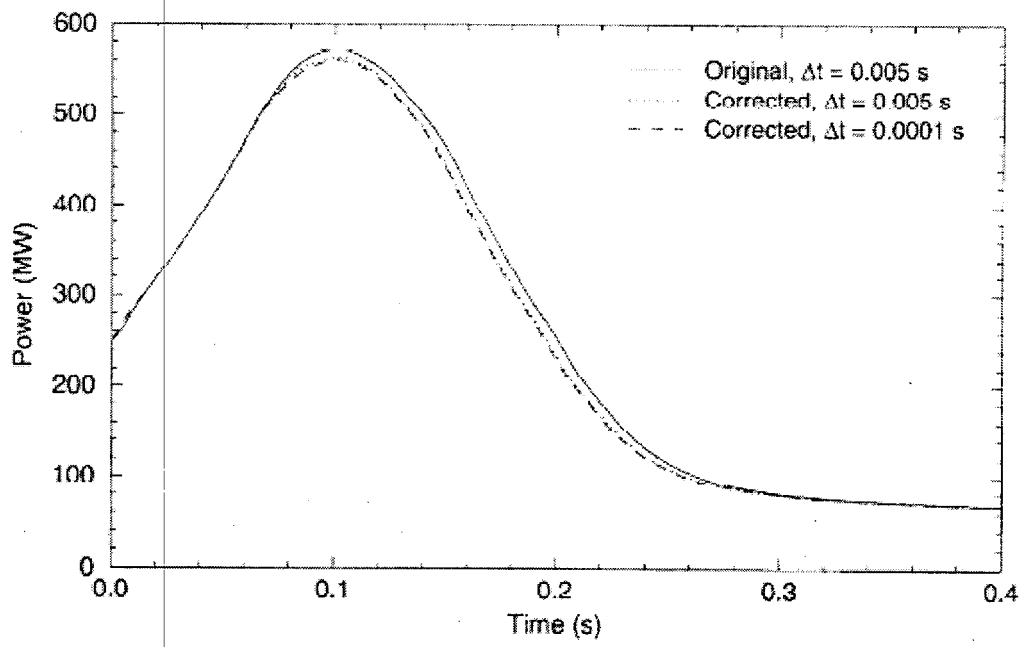

Figure 5. Core power vs. time during limiting Condition 4 RIA (experiment loop large pipe break).

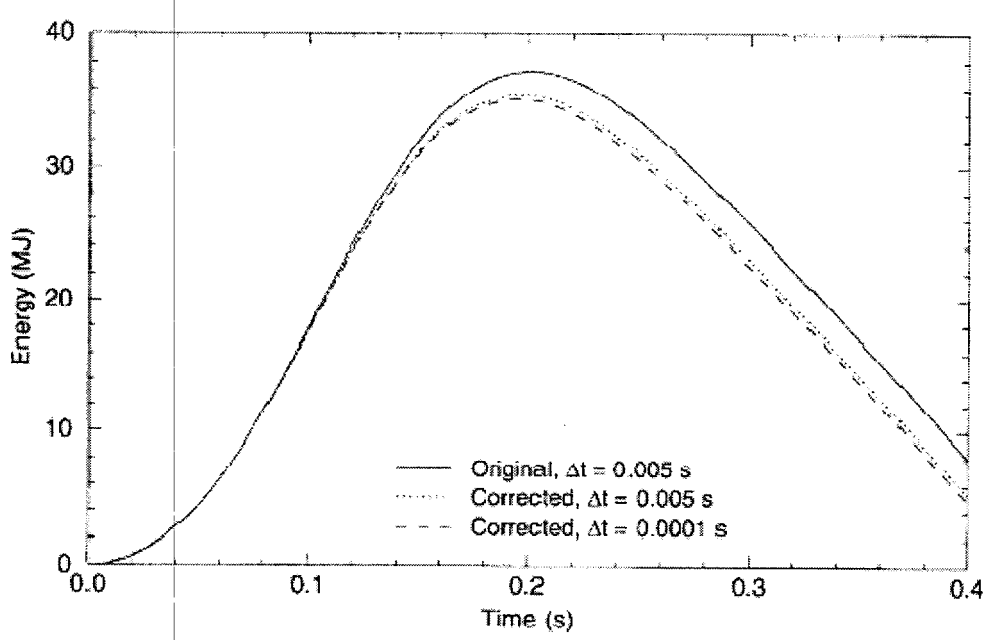

Figure 6. Core energy deposition vs. time during limiting Condition 4 RIA (experiment loop large pipe break).

5.2.3.4 Pressure Tube Flow Bypass Due to a Maximum Useful Capacity Holder (MUCH) Test Train Failure with a Loop Scram (SAR-153, Section 15.4.7.10)

This is a Condition 3 reactivity fault in SAR-153. The MUCH configuration utilizes the experiment shroud as the flow tube. A failure of the shroud or test train would result in a bypass of flow from the inlet to the outlet. This will result in void formation and a positive reactivity insertion. Analyses have shown that the peak insertion for this fault is 0.39$ (for a total IPT voiding of 0.80$) when the loop experiment flow scram occurs at 1.45 s. This insertion is less than a 0.50$ step, and the consequences are bounded by the event discussed in SAR-153, Section 15.4.5.

The calculations in Reference 15 and discussed in SAR-153, Section 15.4.7.10, were updated in ECAR-402 with and without the RELAP5 code error correction. In addition, the calculation with the corrected code incorporates a revised time step size of 0.0001 s. The original calculation was performed with a time step size of 0.005 s. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 4. ECAR-402 Results for MUCH Flow Bypass RIA.

Parameter	Calculation		
	Original	Corrected	Revised Time Step
Scram Time (s)	0.4800	0.4850	0.4843
Maximum Core Power (MW)	307.07	306.88	306.88
Maximum Energy Deposition (MJ)	16.877	16.883	16.834

As shown above in Table 4 and in Figures 7 and 8, the original and corrected calculations were nearly identical and both calculations bounded the revised time step calculation (the most accurate of the calculations). The maximum core power and core energy deposition decreased when the time step size was reduced, primarily because the scram time was calculated more accurately.

This Condition 3 fault is bounded by the limiting Condition 3 fault discussed above in Section 5.2.3.2 (SAR-153, Section 15.4.5). The error in RELAP5 does not change the conclusion of SAR-153, Section 15.4.7.10. It should be noted that in the original analysis, the void worth of the IPT was assumed to be 1.15$. The maximum void worth of a Standard IPT (SIPT) is currently limited to 0.80$. Also, the reactor overpower scram precedes the experiment loop scram during this accident. Therefore, the reactor scrammed on high power (300 MW) rather than low experiment flow.

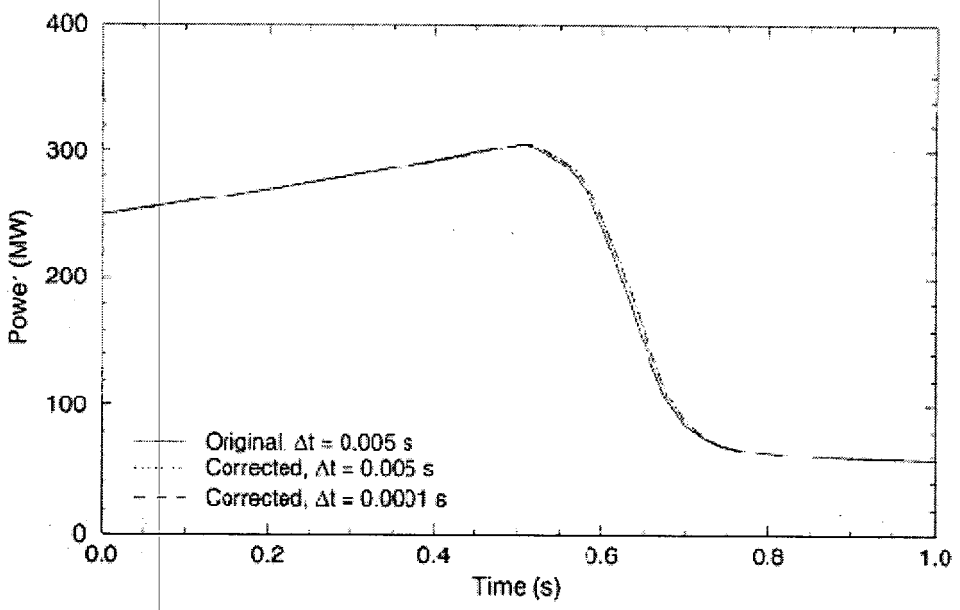

Figure 7. Core power vs. time (MUCH flow bypass with loop scram).

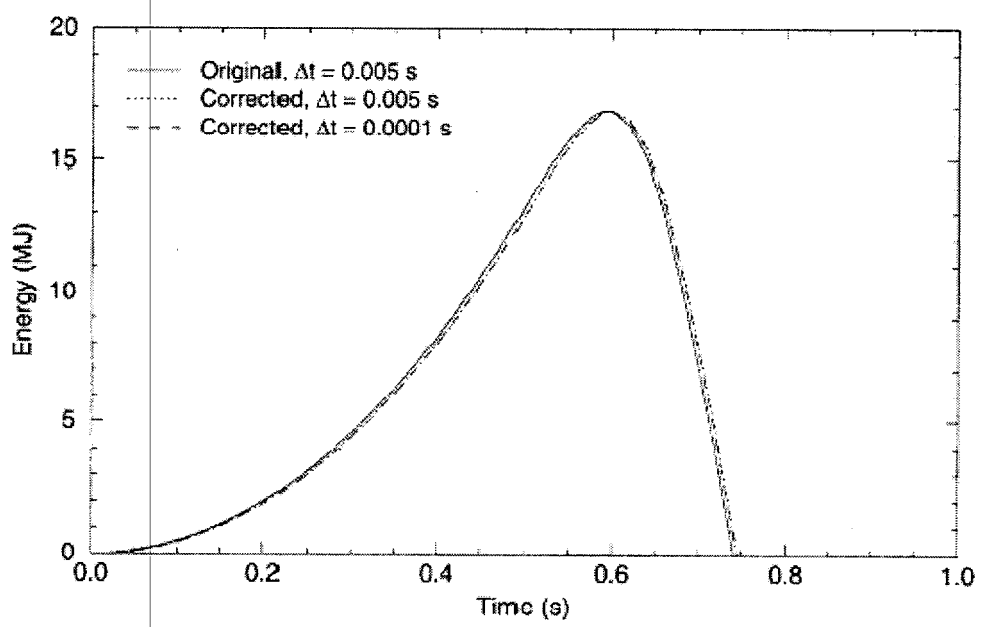

Figure 8. Core energy deposition vs. time (MUCH flow bypass with loop scram).

5.2.3.5 Withdrawal of All Outer Shims from 10^{-10} N_F with Failure of the Wide Range Subsystem (WRS) (SAR-153, Section 15.4.7.14)

This is a Condition 4 reactivity fault in SAR-153. As discussed in SAR-153, Section 15.4.2, the maximum ramp rate for this fault is 0.053$/s. Analysis for an unlimited ramp insertion of 0.079$/s showed that the PPS neutron level subsystem with a reactor trip at 1.2 N_F would limit power to 312 MW which is 4% above the trip setting. As described in SAR-153, Section 15.4.2, the margins to CHF are greater than 3.0σ for more than 7.2% (321.6 MW) above the trip setting. This event is acceptable as a Condition 4 event for both two and three-pump operation since CHF does not occur.

The calculations in Reference 16 and discussed in SAR-153, Section 15.4.7.14, were updated in ECAR-402 with and without the RELAP5 code error correction. In addition, the calculation with the corrected code incorporates a revised time step size of 0.0001 s. The original calculation was performed with a time step size of 0.002 to 0.008 s. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 5. ECAR-402 Results for Outer Shim Withdrawal with WRS Failure.

Parameter	Calculation		
	Original	Corrected	Revised Time Step
Scram Time (s)	13.9900	13.9900	13.9897
Maximum Core Power (MW)	312.76	312.69	312.45
Maximum Energy Deposition (MJ)	188.18	187.87	187.49

The results of the original calculation, the corrected calculation, and the revised time step calculation are shown in Table 5 and Figures 9 and 10. The results of the three calculations were not significantly different. This is a much slower developing accident than analyzed above. It therefore takes considerably longer to reach the scram setpoint (300 MW). As a result, when the calculations were stopped, the core energy deposition was higher than for the accidents analyzed above. Because the energy deposition rate is relatively low, the energy is easily removed by heat transfer to the coolant.

The maximum core power in all three cases was less than 321.6 MW. Therefore, as discussed in SAR-153, Section 15.4.7.14, this Condition 4 fault meets the acceptance criteria for Condition 2 faults. The error in RELAP5 does not change the conclusion of SAR-153, Section 15.4.7.14.

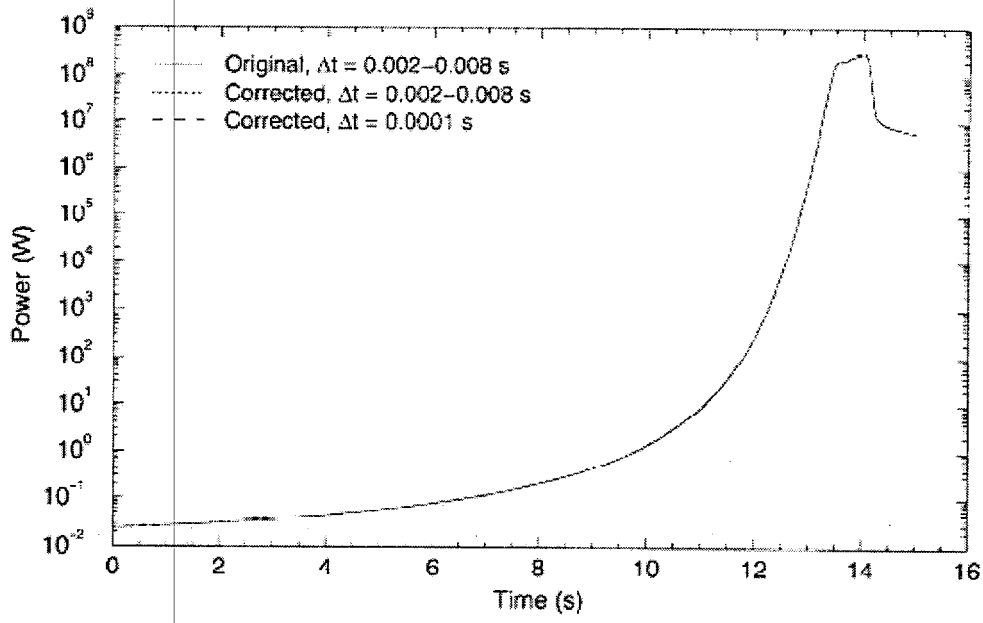

Figure 9. Core power vs. time (0.079$/s from 10-10 NF, scram at 300 MW).

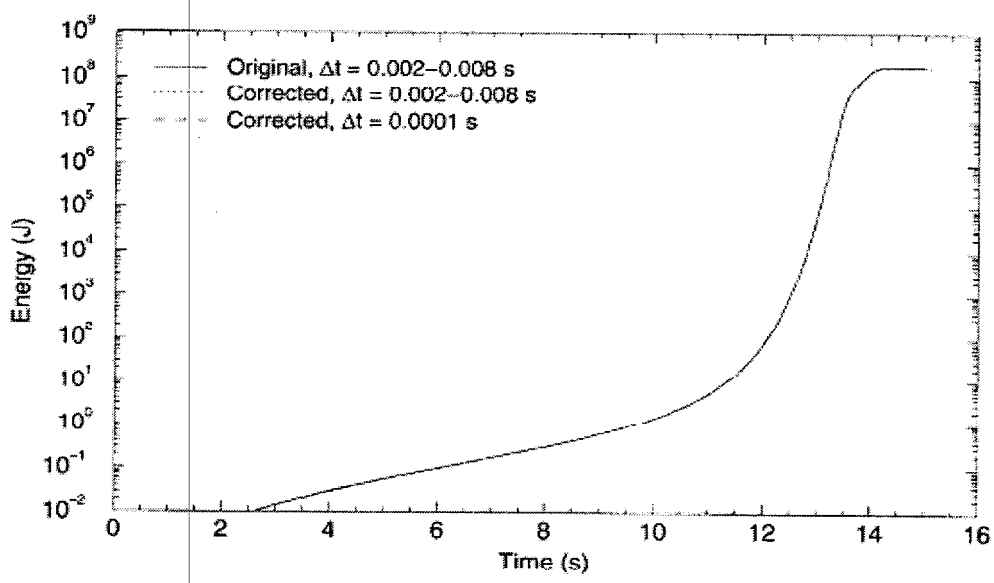

Figure 10. Core energy deposition vs. time (0.079$/s from 10^{-10} N_F, scram at 300 MW).

5.2.3.6 Withdrawal of All Outer Shims and Neck Shims from 10^{-5} N_F Coupled with Rapid Regulating Rod Withdrawal at 10^{-3} N_F (SAR-153, Section 15.4.7.17)

This is a Condition 4 reactivity fault in SAR-153. This fault is a combination of the faults described in SAR-153, Sections 15.4.7.1 and 15.4.2, with concurrent failure of the shim withdrawal permit interlock when the regulating rod is below 20 in. withdrawn. The combined accident is a ramp of 0.079$/s from 10^{-5} N_F to 10^{-3} N_F, then 1.129$/s (0.079$/s from the outer shim cylinders plus 1.05$/s from the regulating rod) for 0.543 s (total regulating rod insertion is 0.57$), then an unlimited ramp at 0.079$/s. Analysis of this event demonstrates that the WRS terminates the event before the regulating rod withdrawal begins. The power level does not reach 10^{-3} N_F.

The calculations in Reference 16 and discussed in SAR-153, Section 15.4.7.17, were updated in ECAR-402 with and without the RELAP5 code error correction. In addition, the calculation with the corrected code incorporates a revised time step size of 0.0001 s. The original calculation was performed with a time step size of 0.002 to 0.008 s. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 6. ECAR-402 Results for Outer Shim Withdrawal with WRS Scram.

Parameter	Calculation		
	Original	Corrected	Revised Time Step
Scram Time (s)	9.6920	9.6980	9.6954
Maximum Core Power (MW)	0.097223	0.097397	0.097098
Maximum Energy Deposition (MJ)	0.11640	0.11620	0.11592

The results of the original calculation, the corrected calculation, and the revised time step calculation are shown in Table 6 and Figures 11 and 12. The results of the three calculations are not significantly different. The acceptance criterion for Condition 4 faults is met. The error in RELAP5 does not change the conclusion of SAR-153, Section 15.4.7.17.

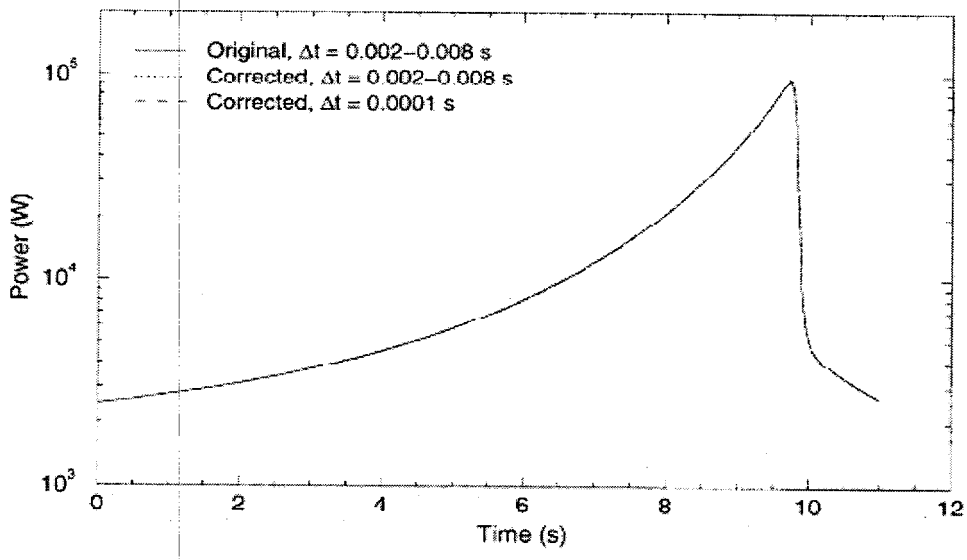

Figure 11. Core power vs. time (0.079$/s from 10^{-5} N_F coupled with regulating rod-cock, wide range scram).

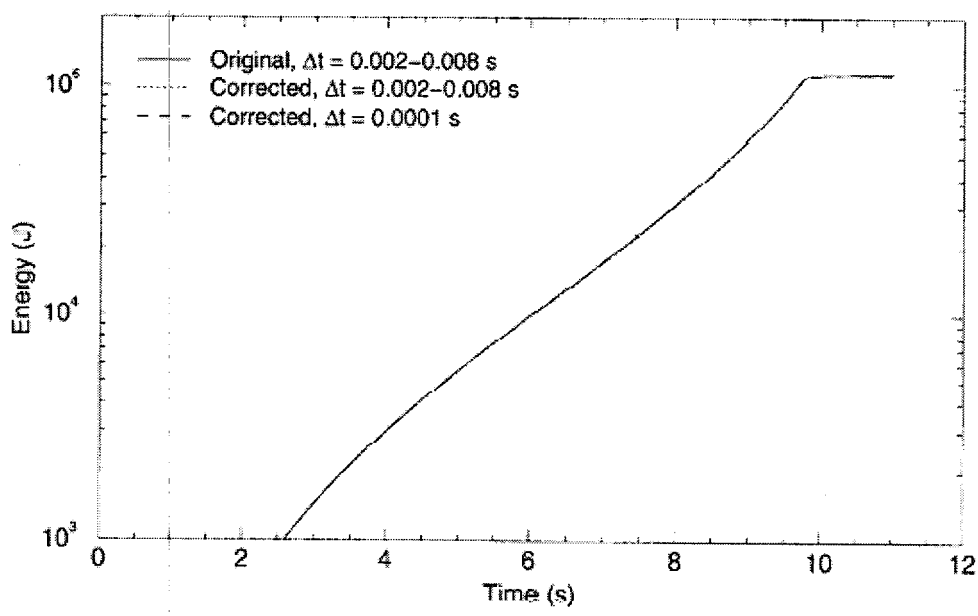

Figure 12. Core energy deposition vs. time (0.079$/s from 10^{-5} N_F coupled with regulating rod-cock, wide range scram).

5.2.3.7 Voiding in All IPTs Due to Simultaneous Flow Coastdown in All Experiment Loops (SAR-153, Section 15.4.7.19)

This is a Condition 4 reactivity fault in SAR-153. Failure of the commercial and diesel power sources will result in simultaneous coastdown of all loop pumps. If the loop scrams fail, voiding in all IPTs could occur. Concurrent failure of the loop protective system is assumed, so no reactor scram will occur until the neutron level PPS subsystems trip at 1.2 N_F.

The calculations in Reference 14 and discussed in SAR-153, Section 15.4.7.19, were updated in ECAR-402 with and without the RELAP5 code error correction. In addition, the calculation with the corrected code incorporates a revised time step size of 0.005 and 0.0001 s. The original calculation was performed with a time step size of 0.005 s. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 7. ECAR-402 Results for Simultaneous Flow Coastdown in all Experiment Loops.

Parameter	Calculation		
	Original	Corrected	Revised Time Step
Scram Time (s)	0.4450	0.4450	0.4513
Maximum Core Power (MW)	307.27	307.85	307.42
Maximum Energy Deposition (MJ)	16.051	16.418	16.159

The results of the original calculation, the corrected calculation, and the revised time step calculation are shown in Table 7 and Figures 13 and 14. The maximum core power in all three cases was less than 321.6 MW. Therefore, as discussed in SAR-153, Section 15.4.7.19, this Condition 4 fault meets the acceptance criteria for Condition 2 faults. The error in RELAP5 does not change the conclusion of SAR-153, Section 15.4.7.19.

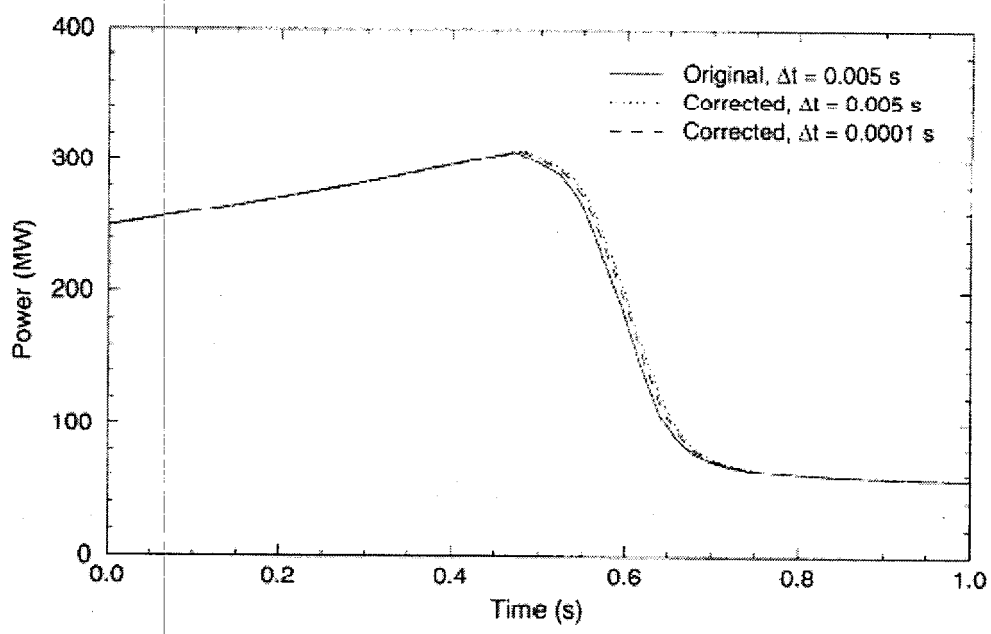

Figure 13. Core power vs. time (simultaneous flow coast down in all experiment loops).

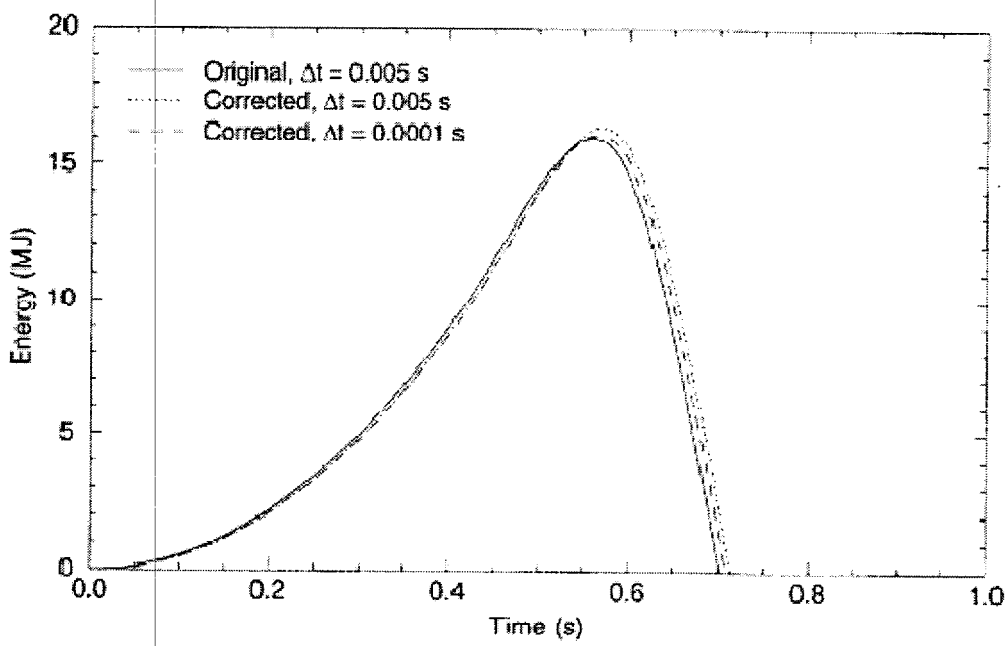

Figure 14. Core energy deposition vs. time (simultaneous flow coast down in all experiment loops).

5.2.4 Depressurized Operations Events (SAR-153, Section 15.9)

A core power limit is used to demonstrate that the fuel is protected in RIAs assumed to occur during ATR depressurized operation. If the maximum core power is less than 7.3 MW, then the margins to CHF and FI are at least 3σ, and the acceptance criteria for Condition 2, 3, and 4 faults are met. The scram setpoint for the calculations in this section was 1.15 MW (2.3 N_L), with a response time of 0.035 s.

5.2.4.1 0.30$/s Ramp Insertion (SAR-153, Section 15.9.3)

Most of the reactivity accidents in SAR-153, Section 15.9.3, are bounded by the 0.30$/s ramp insertion analyzed in Reference 17. The calculation was rerun with and without the error correction. The initial core power in the corrected calculation was somewhat lower than that in the original calculation (48.1 vs. 48.8 kW). The worst starting power was determined as discussed in Reference 17. The time step size in both the original and corrected calculations was 0.0001 s. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 8. ECAR-402 Results for 0.30$/s Ramp Insertion During Depressurized Operation.

Parameter	Calculation	
	Original	Corrected
Scram Time (s)	2.9006	2.9608
Maximum Core Power (MW)	2.1301	2.2469
Maximum Energy Deposition (MJ)	0.82124	0.87720

As shown in Table 8 and Figures 15 and 16, the maximum core power and core energy deposition were somewhat higher in the corrected calculation than in the original calculation (5.5 and 6.8% higher, respectively). In both calculations, the maximum core power was less than the 7.3 MW limit. Therefore, the ATR PPC are met.

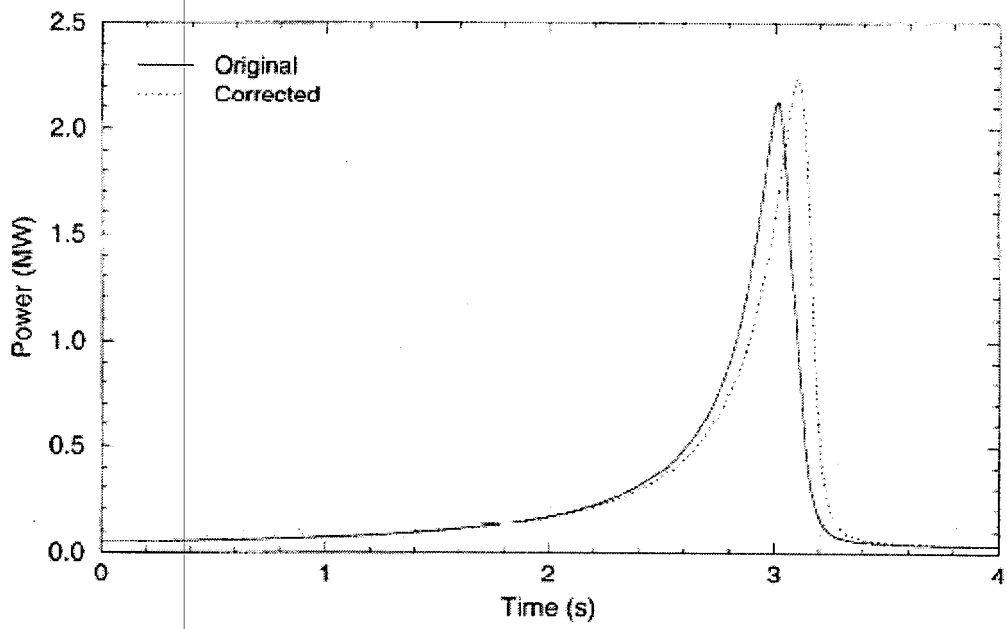

Figure 15. Core power vs. time (0.30$/s ramp insertion, depressurized operation).

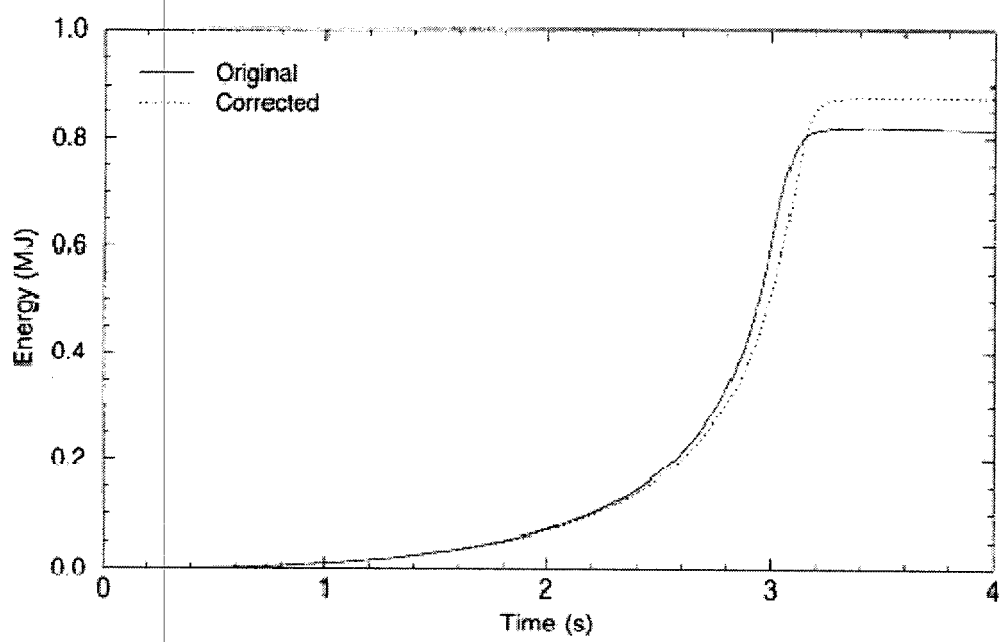

Figure 16. Core energy deposition vs. time (0.30$/s ramp insertion, depressurized operation).

5.2.4.2 Rapid Regulating Rod Withdrawal (SAR-153, Section 15.9.3.2)

This is a Condition 3 reactivity fault in SAR-153. The calculations in Reference 17 and discussed in SAR-153, Section 15.9.3.2, were updated in ECAR-402 with and without the RELAP5 code error correction. The time step size in both the original and corrected calculations was 0.0001 s. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 9. ECAR-402 Results for Rapid Regulating Rod Withdrawal During Depressurized Operation.

Parameter	Calculation	
	Original	Corrected
Scram Time (s)	0.5378	0.5507
Maximum Core Power (MW)	1.3182	1.3176
Maximum Energy Deposition (MJ)	0.29824	0.30654

The results of the original and corrected calculations are shown in Table 9 and Figures 17 and 18. The maximum core energy deposition increased 2.8% when the error was corrected. The maximum core power in each calculation was less than the 7.3 MW limit. Therefore, the ATR PPC are met.

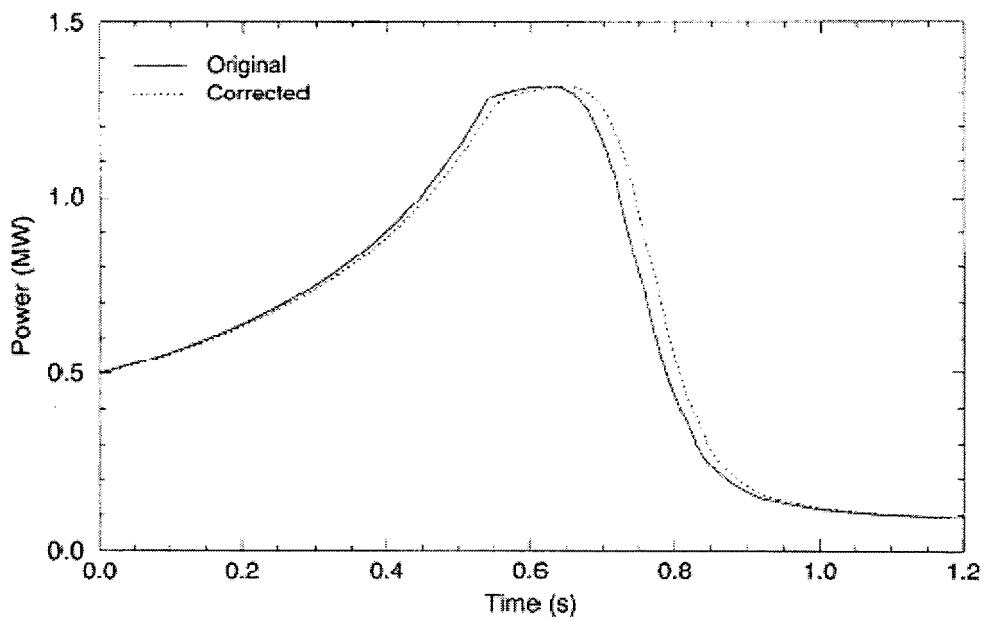

Figure 17. Core power vs. time (rapid regulating rod withdrawal, depressurized operation).

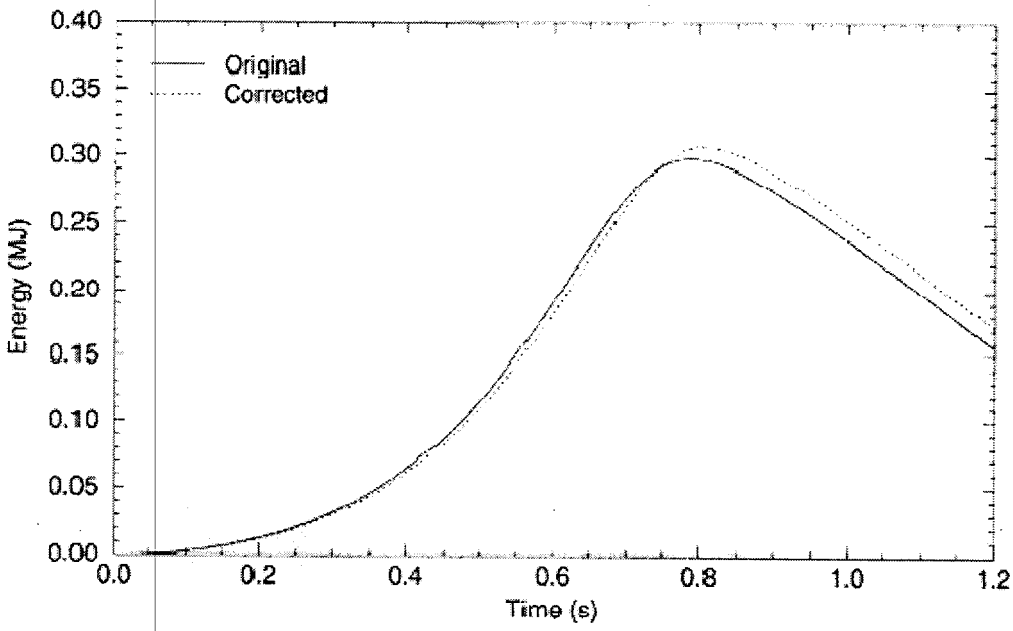

Figure 18. Core energy deposition vs. time (rapid regulating rod withdrawal, depressurized operation).

5.2.4.3 Perched Fuel Element Drop from within Measurement Accuracy (One Inch) (SAR-153, Section 15.9.3.8)

This Condition 3 fault is bounded by the 0.10$ step analyzed in Reference 17. The calculation was rerun with and without the error correction. The time step size in both the original and corrected calculations was 0.00002 s for the first second and 0.001 s thereafter. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 10. ECAR-402 Results for 0.10$ step during depressurized operation.

Parameter	Calculation	
	Original	Corrected
Scram Time (s)	53.202	53.262
Maximum Core Power (MW)	1.1505	1.1505
Maximum Energy Deposition (MJ)	19.181	19.199

As shown in Table 10 and Figures 19 and 20, the original and corrected calculations were not significantly different. The maximum core power in each calculation was less than the 7.3 MW limit. Therefore, the ATR PPC are met.

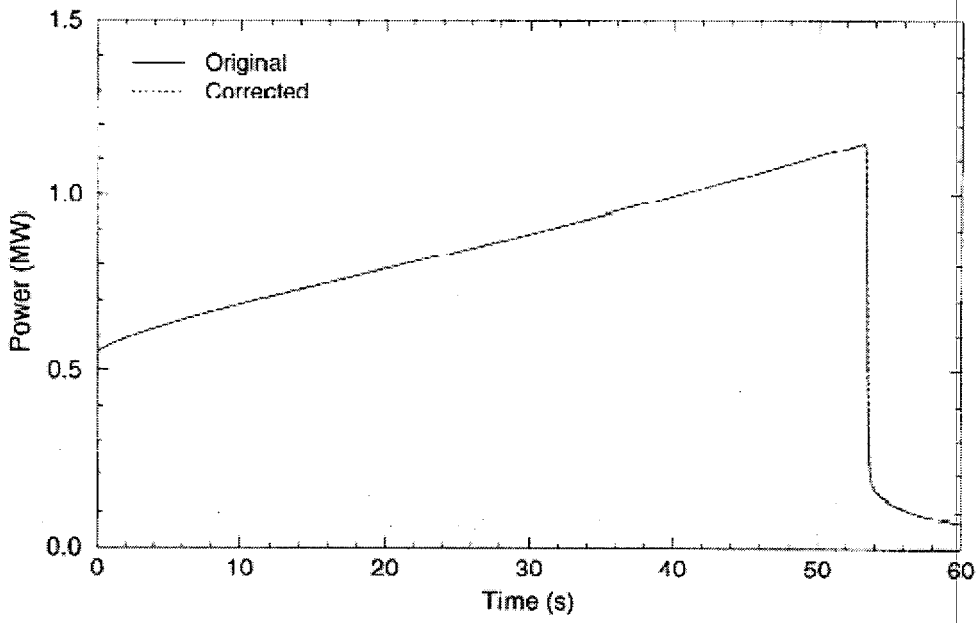

Figure 19. Core power vs. time (0.10$ step, depressurized operation).

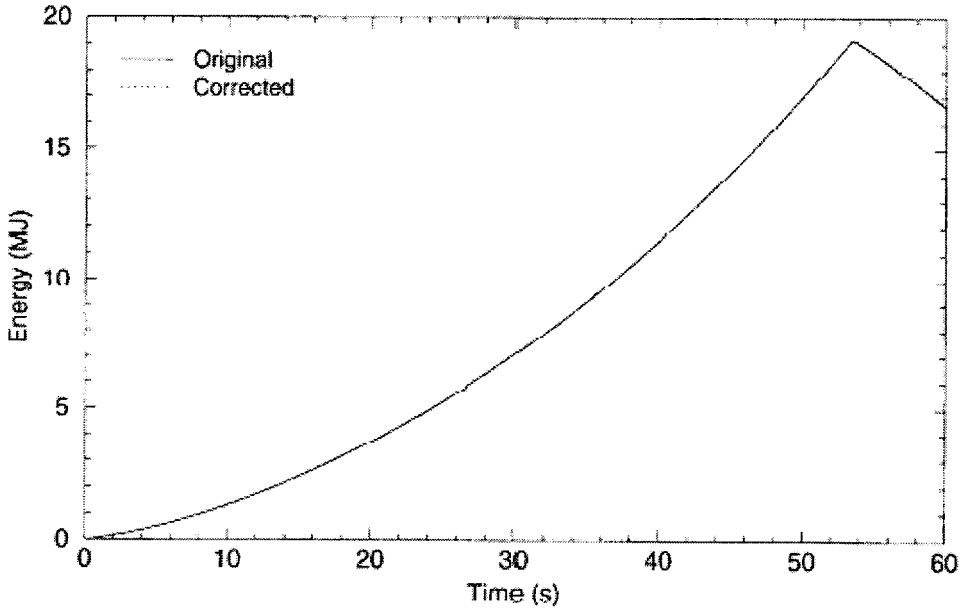

Figure 20. Core energy deposition vs. time (0.10$ step, depressurized operation).

5.2.5 Severe Accident Analyses (SAR-153, Section 15.12)

The scram setpoint for the step reactivity insertion calculations discussed in this section was 20% overpower (300 MW), with a response time of 0.025 s.

5.2.5.1 Anticipated Transients Without Scram (SAR-153, Section 15.12.5)

Two Anticipated Transients Without Scram (ATWS) are discussed in SAR-153, Section 15.12.5. The accidents are initiated by: (a) PCP coastdown due to a loss of commercial power (one emergency coolant pump continues to operate) and (b) positive reactivity insertion due to an experiment loop 1/2-in. pipe break. The original calculations, which are documented in Reference 18, were rerun with and without the error correction.

PCP coastdown is a relatively slow transient. The original time step size ranged from 0.05 to 0.08 s. The revised calculation was performed with the time step size cut in half (0.025 to 0.04 s). The time step size for the experiment loop 1/2-in. pipe break was originally 0.005 to 0.008 s. The revised calculation was performed with the time step size cut in half (0.0025 to 0.004 s). The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 11. ECAR-402 results for Anticipated Transients Without Scram.

PCP coastdown			Experiment loop 1/2-in. pipe break		
Core Power at 150 s (MW)			Maximum Core Power (MW)		
Original	Corrected	Revised Time Step	Original	Corrected	Revised Time Step
29.518	29.517	29.518	411.37	411.42	411.38

As shown in Table 11 and Figures 21 and 22, the RELAP5 error had negligible effect on the original calculations. The conclusions of the original analysis remain valid with the revised calculations.

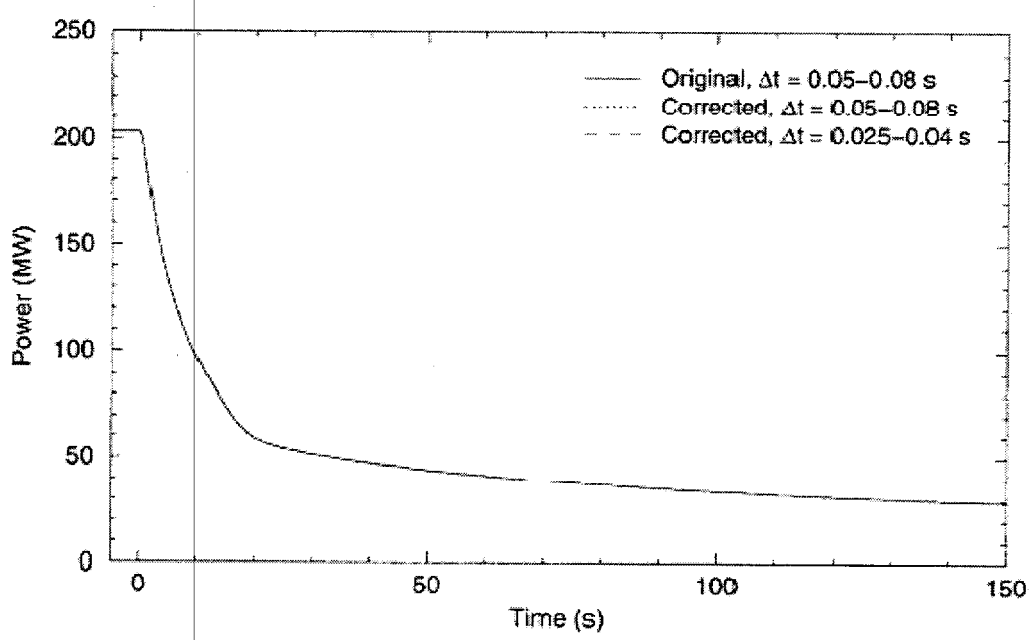

Figure 21. Core power vs. time (PCP coast down without scram).

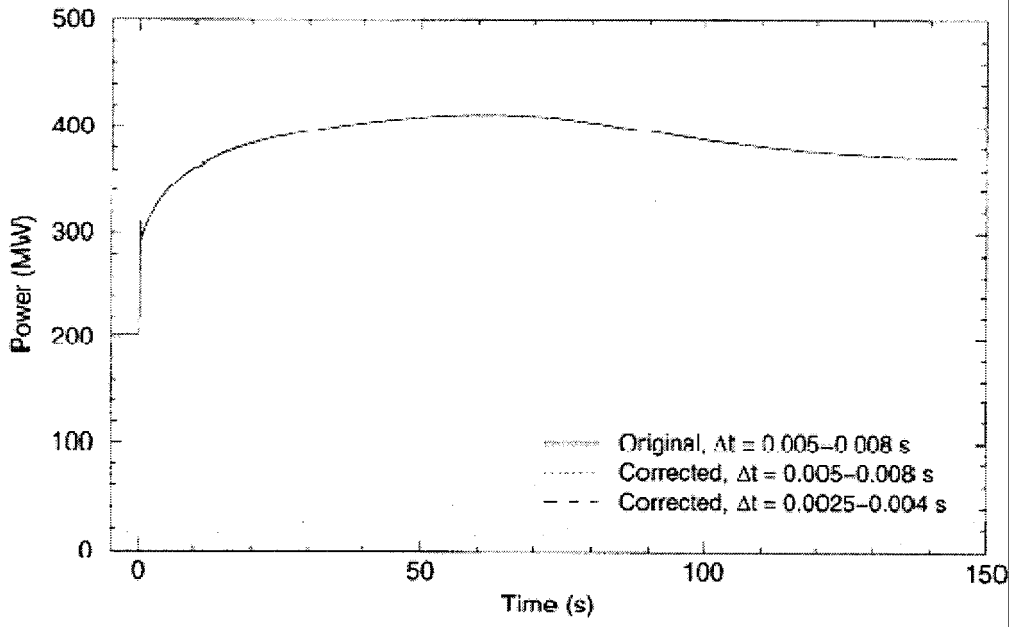

Figure 22. Core power vs. time (experiment loop 1/2-in. pipe break without scram).

5.2.5.2 Very Large RIA (1.30$ Step) (SAR-153, Section 15.12.6)

This accident, which is documented in Reference 19, was originally simulated with the RELAP4 code. As noted in Reference 10, the reactor kinetics coding in RELAP4 and RELAP5 are different. The error in the RELAP5 code was not present in the RELAP4 code. A 1.30$ step was simulated with RELAP5/MOD3 to investigate the effect of the error on a very large RIA. The time step size in the original and corrected calculations was 0.0001 s; a revised calculation was performed with the time step size reduced to 0.00005 s. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 12. ECAR-402 results for 1.30$ step insertion.

Parameter	Calculation		
	Original[(a)]	Corrected	Revised Time Step
Scram Time (s)	0.0260	0.0260	0.0259
Maximum Core Power (MW)	4261.2	4259.9	4255.5
Maximum Energy Deposition (MJ)	174.39	174.38	175.52
Note (a) 1.30$ RELAP4 calculation reran using RELAP5/MOD3.			

The maximum core power and core energy deposition in the RELAP5 calculations were higher than in the RELAP4 calculation. The maximum power in the RELAP4 calculation was approximately 3510 MW as shown in Figure 28 of Reference 19. Negative reactivity feedback may have been greater in the RELAP4 calculation than in the RELAP5 calculations. As shown in Table 12 and Figures 23 and 24, the RELAP5 error had negligible effect on the original calculations. The conclusions of the original analysis remain valid with the revised calculations.

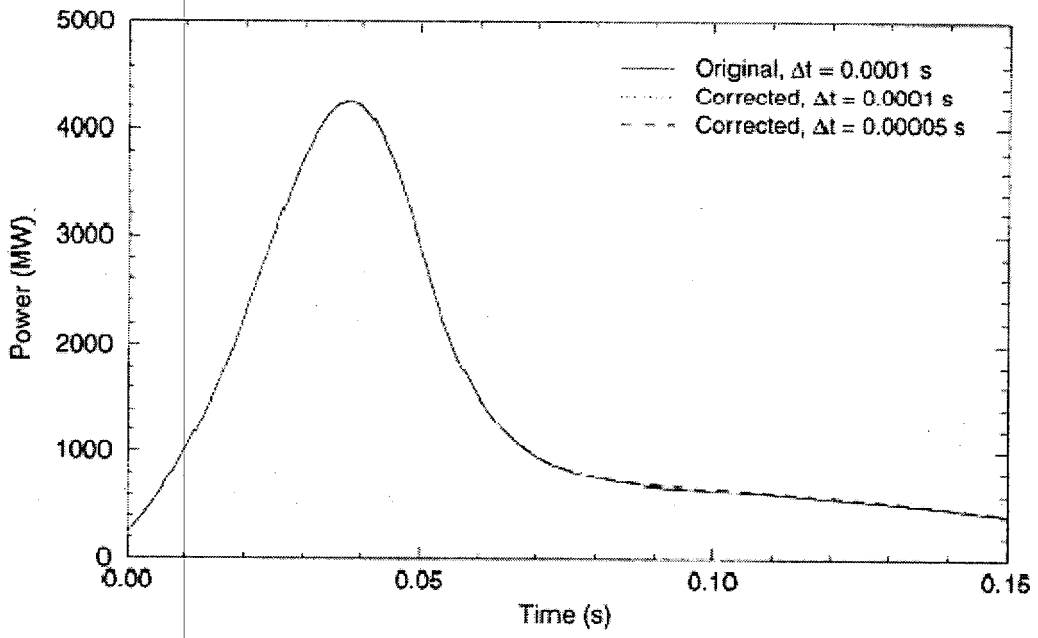

Figure 23. Core power vs. time (1.30$ step).

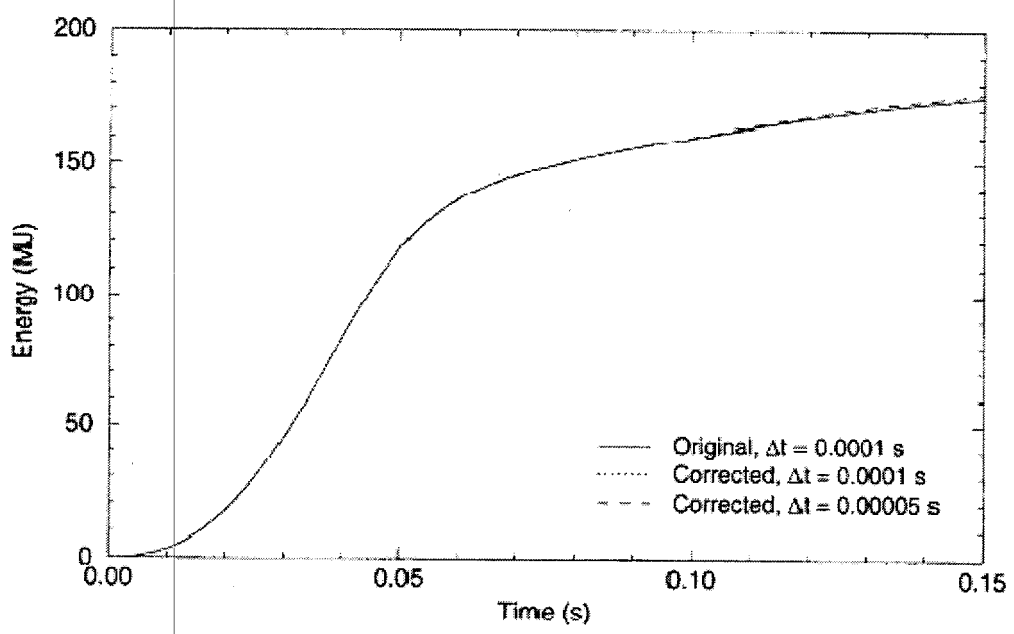

Figure 24. Core energy deposition vs. time (1.30$ step).

5.2.5.3 Direct Damage Large RIA (SAR-153, Section 15.12.7)

This accident is initiated by the rupture of an IPT inside the core and is described as being "nearly equivalent to a 0.90$ step." A 0.90$ step was simulated with RELAP5/MOD3 to investigate the effect of the reactor kinetics error on a large RIA. The time step size in the original and corrected calculations was 0.0001 s; a revised calculation was performed with the time step size reduced to 0.00005 s. The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 13. ECAR-402 results for 0.90$ step insertion.

Parameter	Calculation		
	Original[(a)]	Corrected	Revised Time Step
Scram Time (s)	0.02640	0.02640	0.02630
Maximum Core Power (MW)	1150.9	1150.9	1150.5
Maximum Energy Deposition (MJ)	58.998	59.009	58.971
Note (a) 1.30$ RELAP4 calculation reran using RELAP5/MOD3.			

As shown in Table 13 and Figures 25 and 26, the three calculations were not significantly different. The conclusions of the original analysis remain valid with the revised calculations.

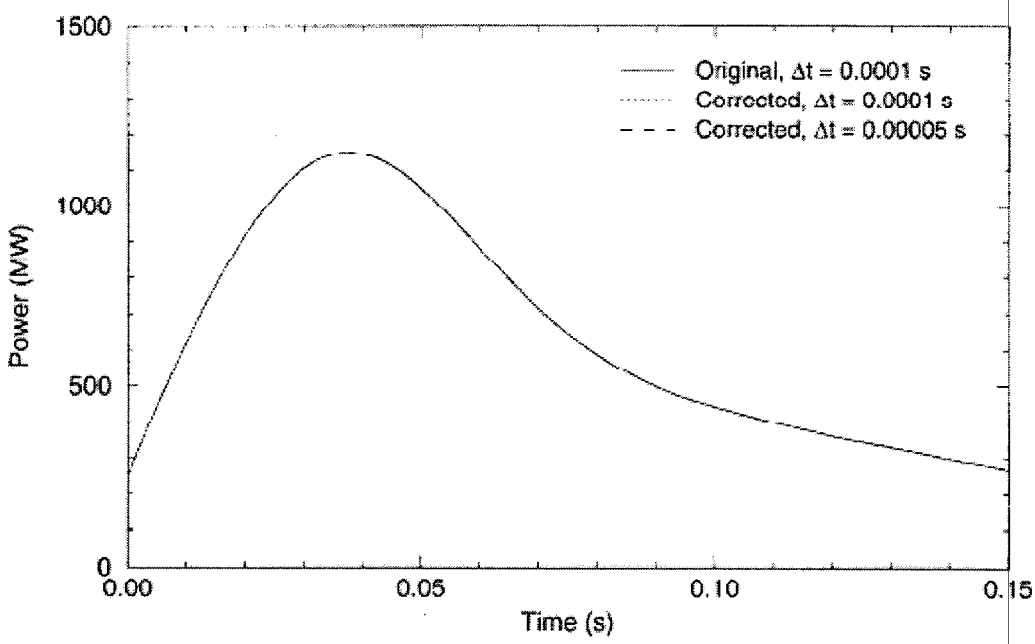

Figure 25. Core power vs. time (0.90$ step).

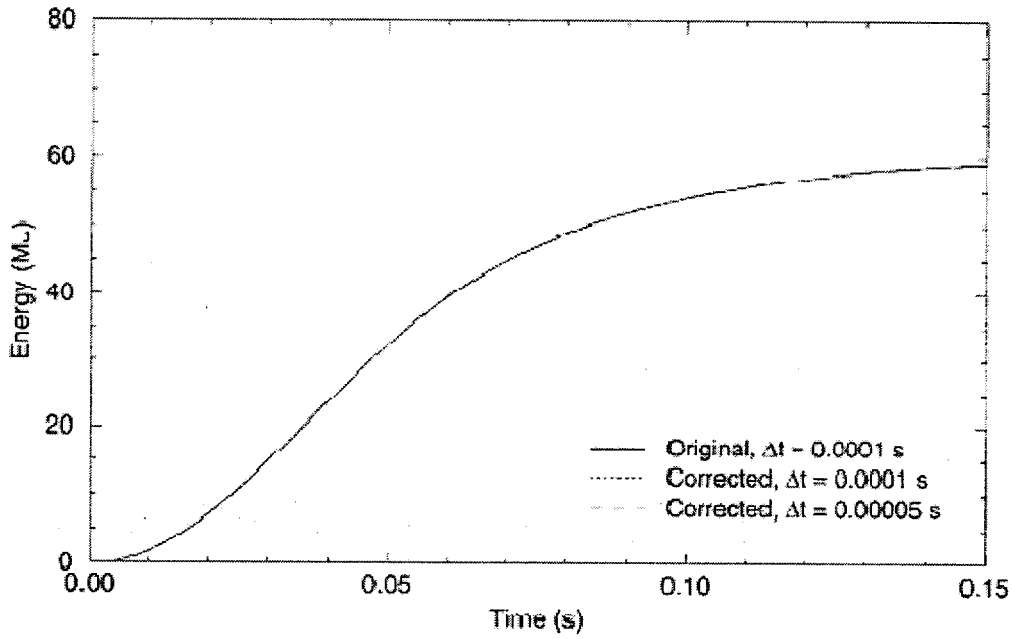

Figure 26. Core energy deposition vs. time (0.90$ step).

5.2.6 Pressurized Water Loop Experiment Facilities (SAR-153, Section 10.2)

Numerous IPT blowdown calculations have been performed with RELAP5 to establish operating limits for pressurized water loop experiments (SAR-153, Section 10.2.6.2.2). The worst Condition 2 and 4 calculations (i.e., small and large experiment loop pipe breaks) have been rerun, with and without the error correction, for each IPT configuration: SIPT, LIPT, SIPT with a MUCH test train, and AHTL IPT with a MUCH test train. The scram setpoint for these calculations was 20% overpower (300 MW), with a response time of 0.025 s.

5.2.6.1 SIPT Small- and Large-Break RIAs

This accident, which is documented in Reference 20, was rerun with and without the error correction to calculate core energy deposition and maximum core energy deposition. The time step size in both the original and corrected calculations was 0.0001 s.

The maximum core power and core energy deposition results from ECAR-402 are as follows:

Table 14. ECAR-402 results for SIPT experiment loop small and large pipe breaks.

Parameter	Small Break		Large Break	
	Original	Corrected	Original	Corrected
Scram Time (s)	0.0596	0.0659	0.0471	0.0475
Maximum Core Power (MW)	376.30	377.51	550.91	546.46
Maximum Energy Deposition (MJ)	11.831	12.802	27.115	29.040

The maximum core powers in the original and revised calculations were comparable. The maximum core energy depositions were higher in the revised calculations than in the original calculations (8.2% higher for the small-break and 7.1% higher for the large break). The revised results as shown in Table 14 are bounded by the SAR Envelope curves as shown in Figures 27 through 30. Therefore, the PPC for Condition 2 and 4 faults are met.

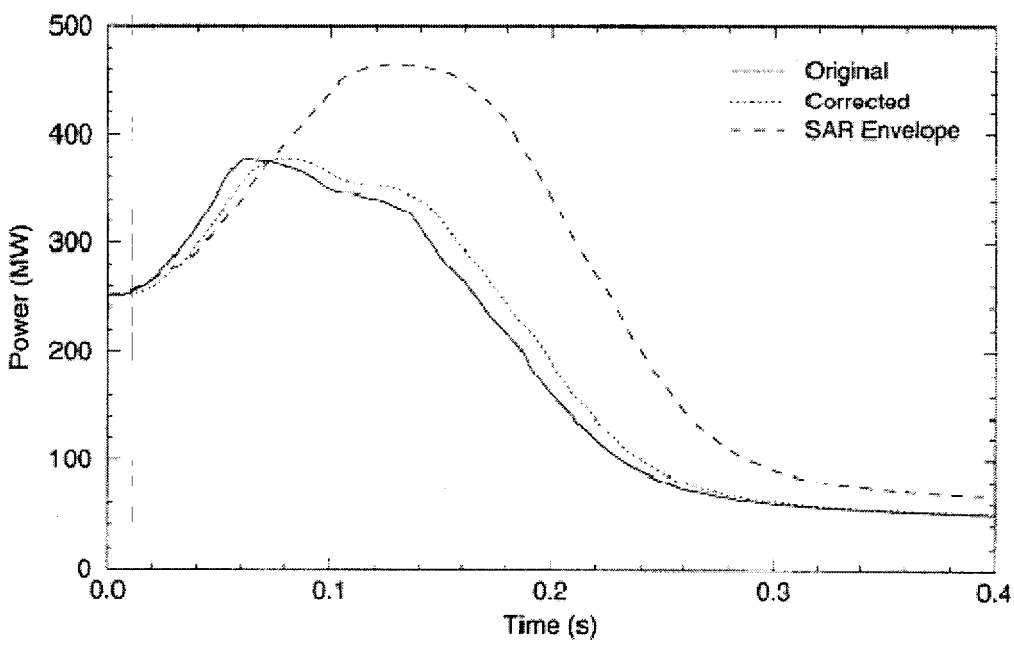

Figure 27. Core power vs. time (SIPT small break).