Validation of ALARA Activation Code for Arbitrary Irradiation Schedules

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Summary

The ALARA [Analytic and Laplacian Adaptive Radioactivity Analysis][i] activation code, previously validated for its accuracy and precision[ii], has now been validated for arbitrary irradiation schedules. Based on the International Atomic Energy Agency [IAEA] Fusion Evaluated Nuclear Data Library [FENDL] Calculational Activation Benchmark[iii], eight irradiation schedules were designed to conserve the total fluence and schedule duration of the benchmark's pulsing problem. In addition to steady-state approximations and hybrid pulsing schemes, the test schedules included pulsing histories with varied pulse heights and increasing levels of complexity. The total calculated activities in 44 non-void zones at a one-hour cooling time were used to compare results for the eight different irradiation histories to the exact pulsing benchmark. Overall, agreement between the exact pulsing case and the testing cases was within 1.92% at all zones and within 0.35% in most zones. The result shows that ALARA is an effective computational tool for the calculation of induced activity caused by complex irradiation schedules.

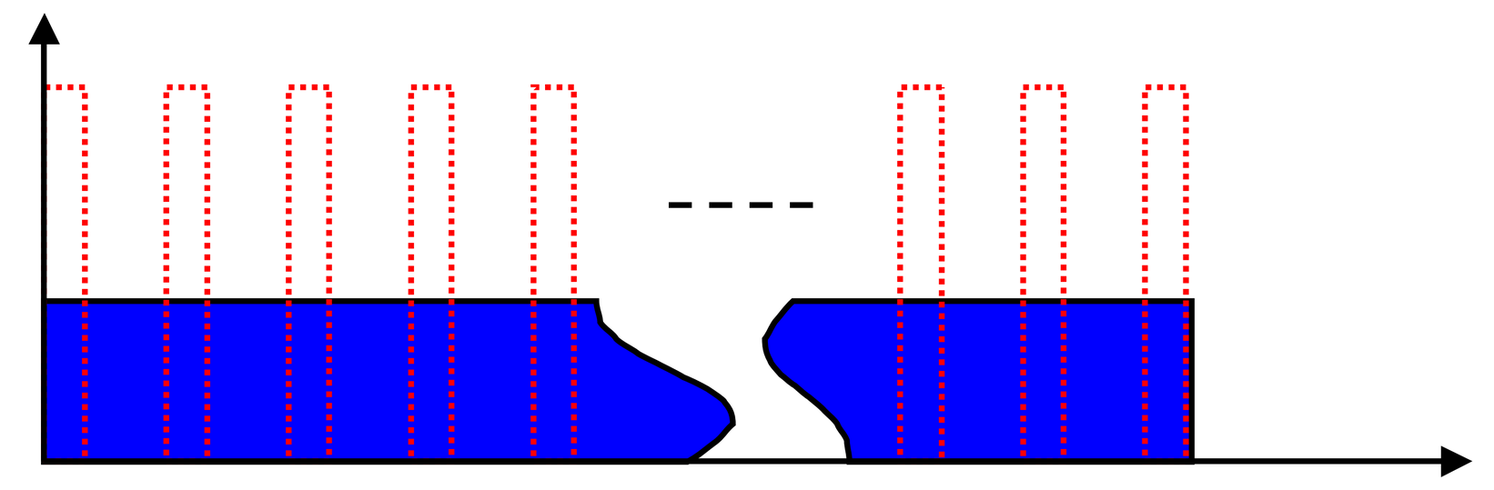
Benchmark Specification

IAEA FENDL Calculational Activation Benchmark

- 1-D radial model (44 zones, 318 intervals).
- Wild variety of material: TF Coils, Pb/B_4C shield, Inconel VV, SS316/H_2O blanket, Be coated Cu FW.
- 175 group neutron fluxes.
- FENDL 2.0 Activation and Decay libraries.
- Benchmark Schedule: 94500 pulses of 1000 s with 1200 s dwell.
- Compare to four approximation schedules and four arbitrary irradiation schedules.

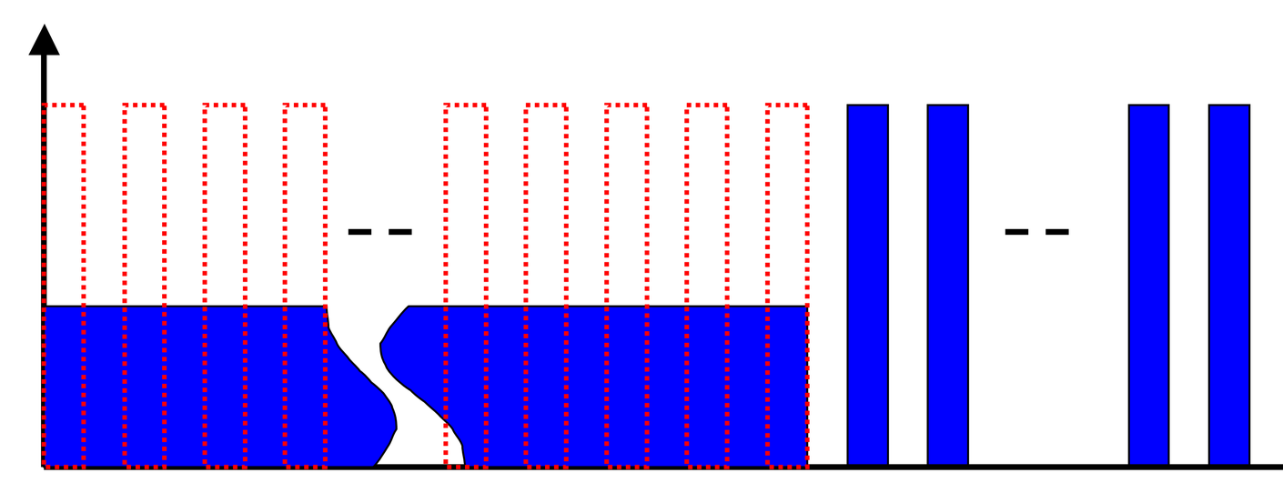
Red-dotted bars represent a benchmark schedule.

Pulsing Approximation



Schedule 1: Steady State.

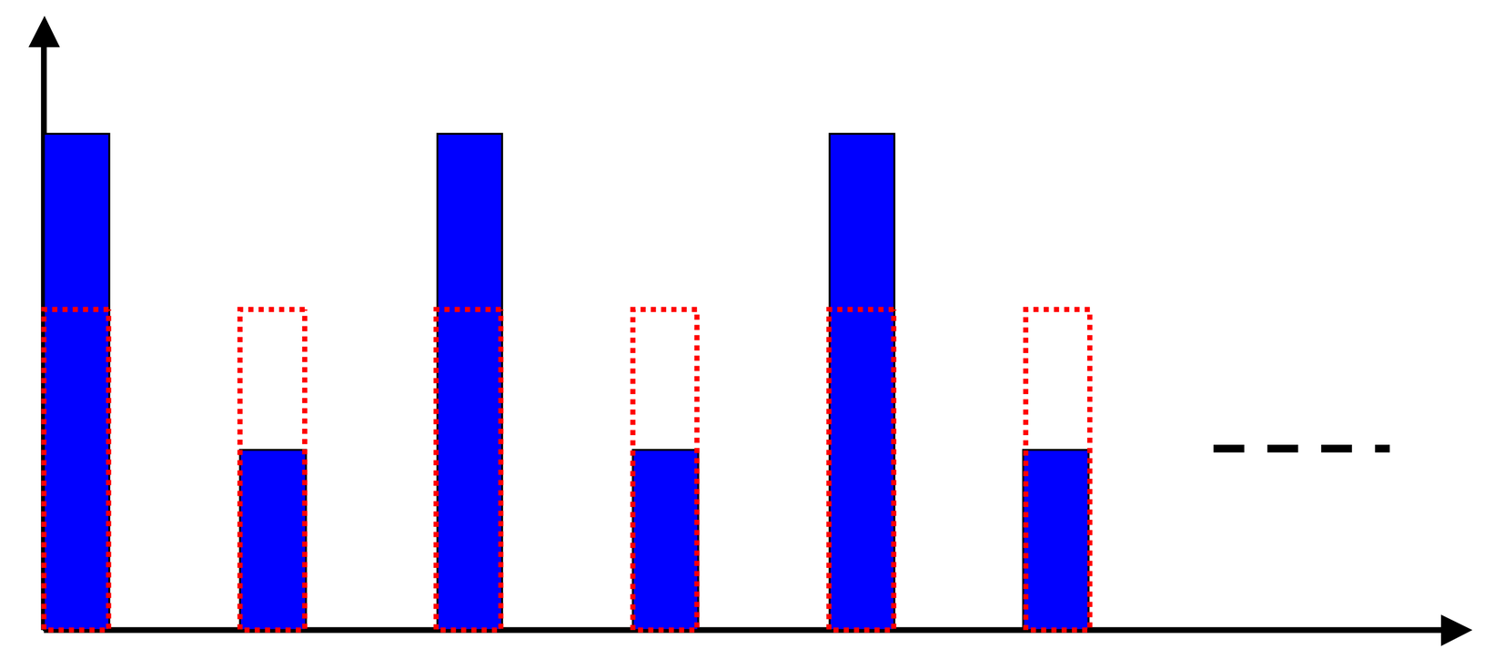
The flux was averaged over the full lifetime such that the total fluence and total operation time are conserved.



Schedule 2, 3 and 4: Hybrid Schedule with 100, 500 and 5000 pulses, respectively.

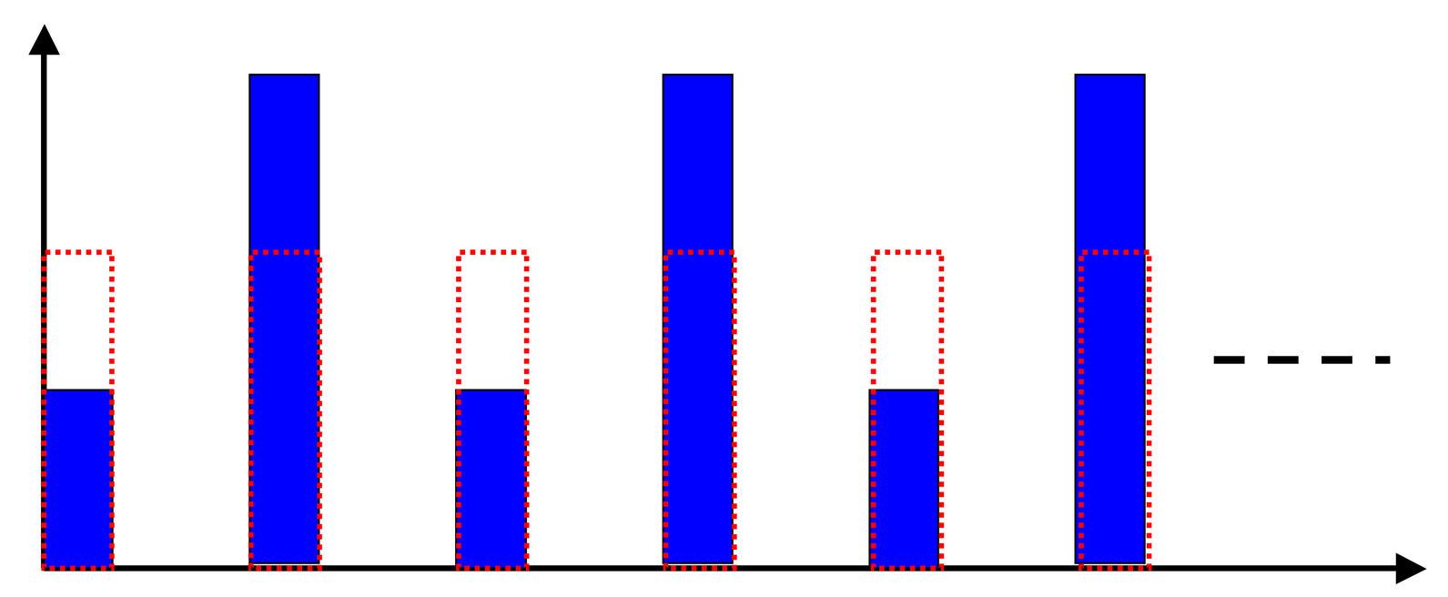
In the hybrid approximation, the majority of the pulses are simulated with steady-state approximation, followed by a number of exact pulses. The three hybrid irradiation schedules studied in this research had 100, 500 and 5000 exact final pulses, respectively.

Arbitrary Irradiation Schedules



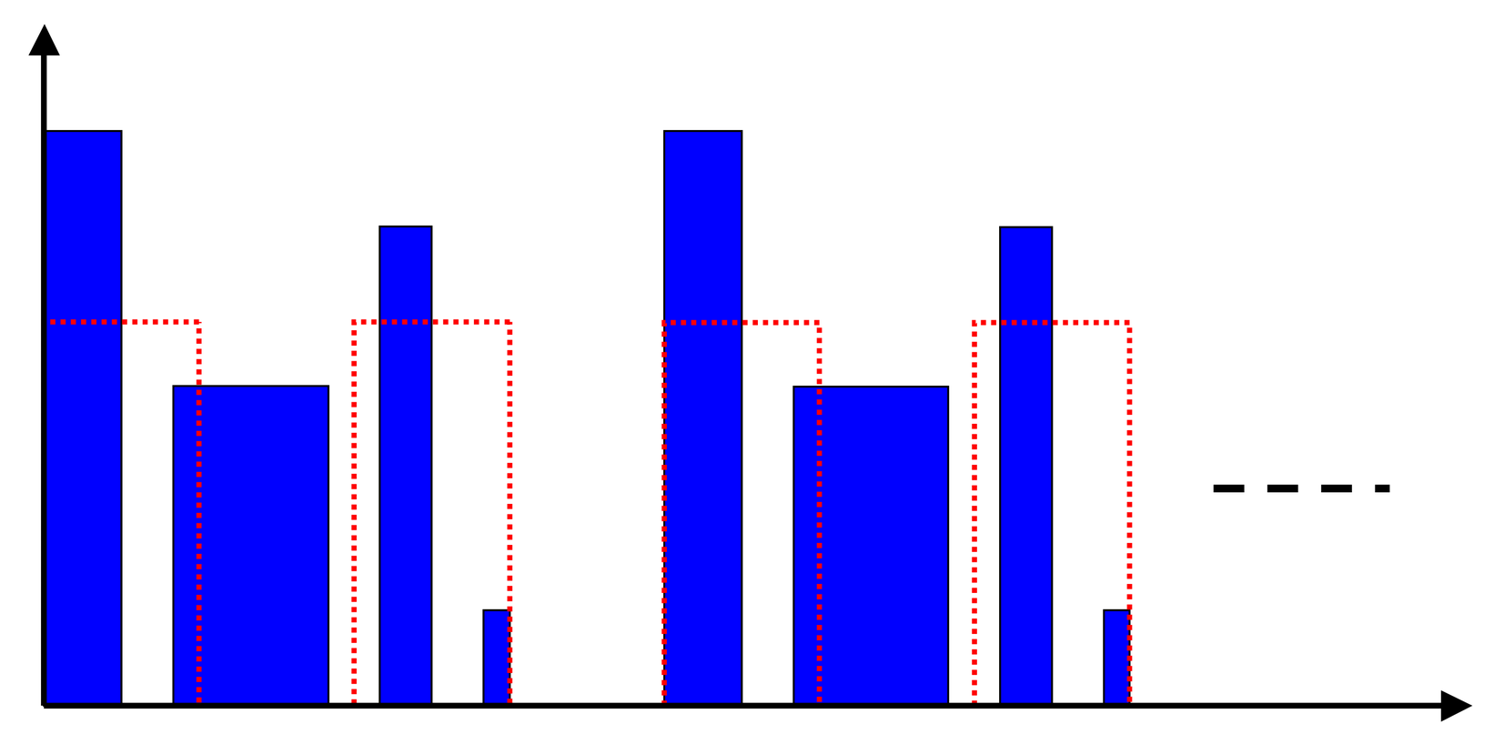
Schedule 5: Hi-Lo Pulsing Schedule.

The fluences of every two pulses of the exact pulsing schedule were made 50% higher and 50% lower, respectively.



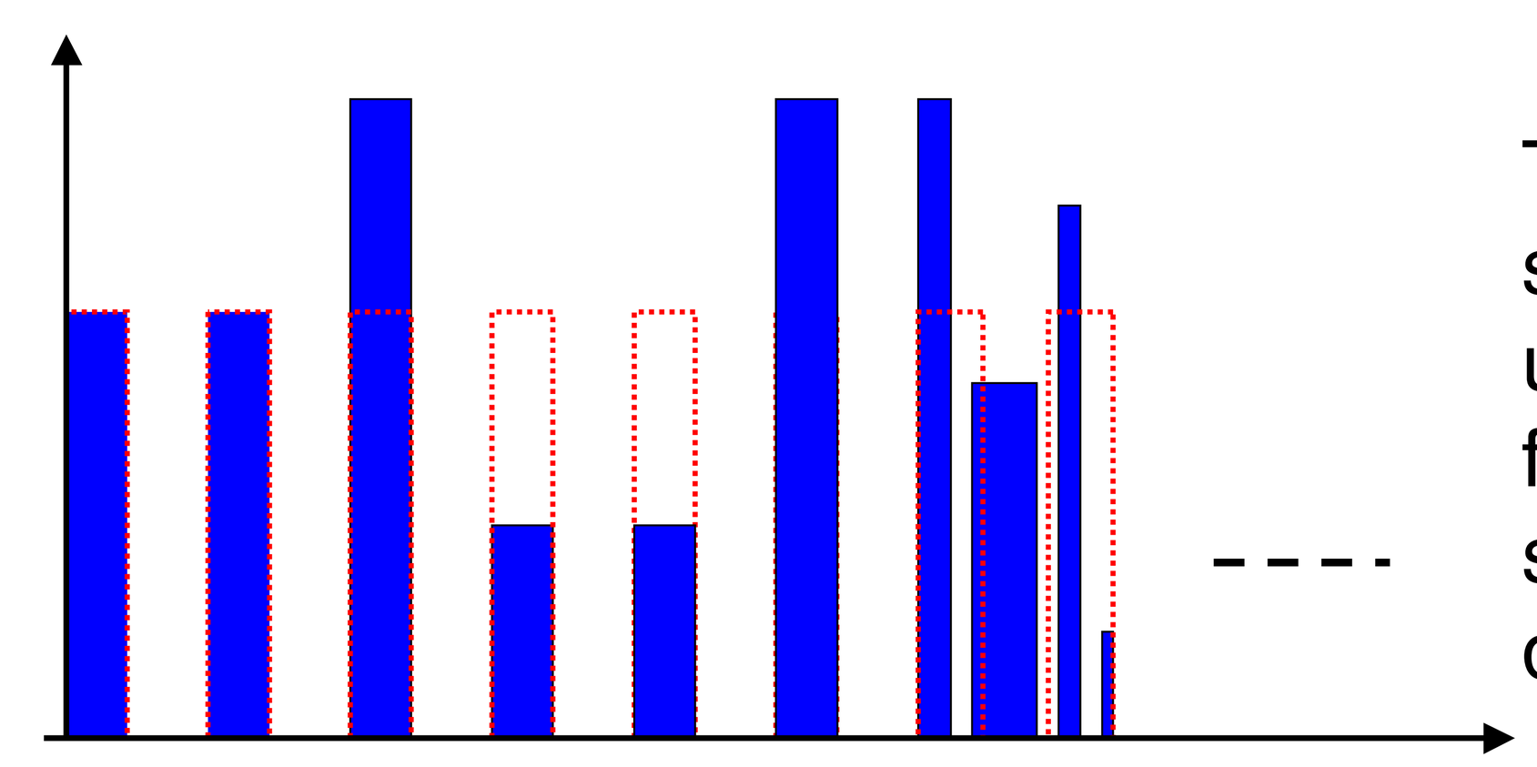
Schedule 6: Lo-Hi Pulsing Schedule.

The fluences of every two pulses of the exact pulsing schedule were made 50% lower and 50% higher, respectively.



Schedule 7: Complex Designed Schedule.

The sub-schedule in schedule 7 contained four different pulses with durations of 500 s, 1000 s, 375 s and 125 s, and relative heights of 1.5, 0.75, 1.25 and 0.25, respectively. The dwell time of each pulse was 400 s. Each sub-schedule was 1200 s apart and repeated 47250 times.

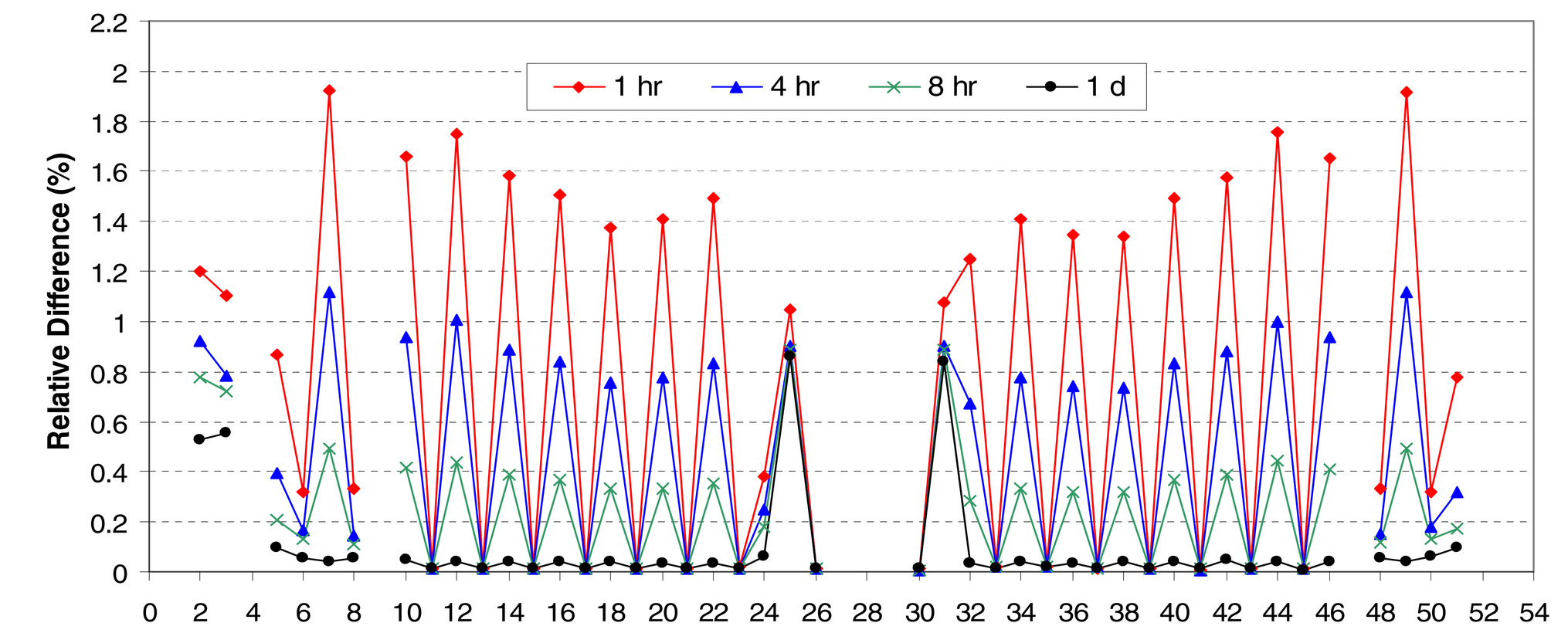


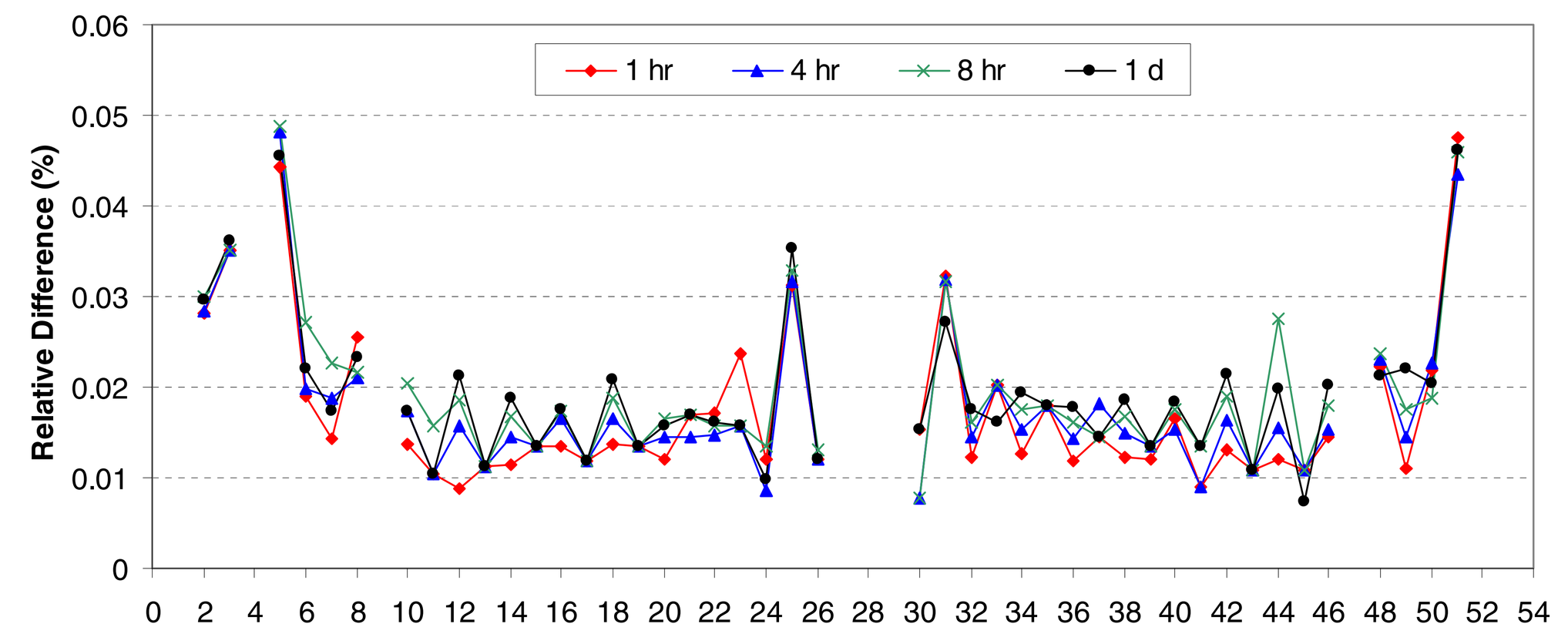
Schedule 8: Combination Schedule.

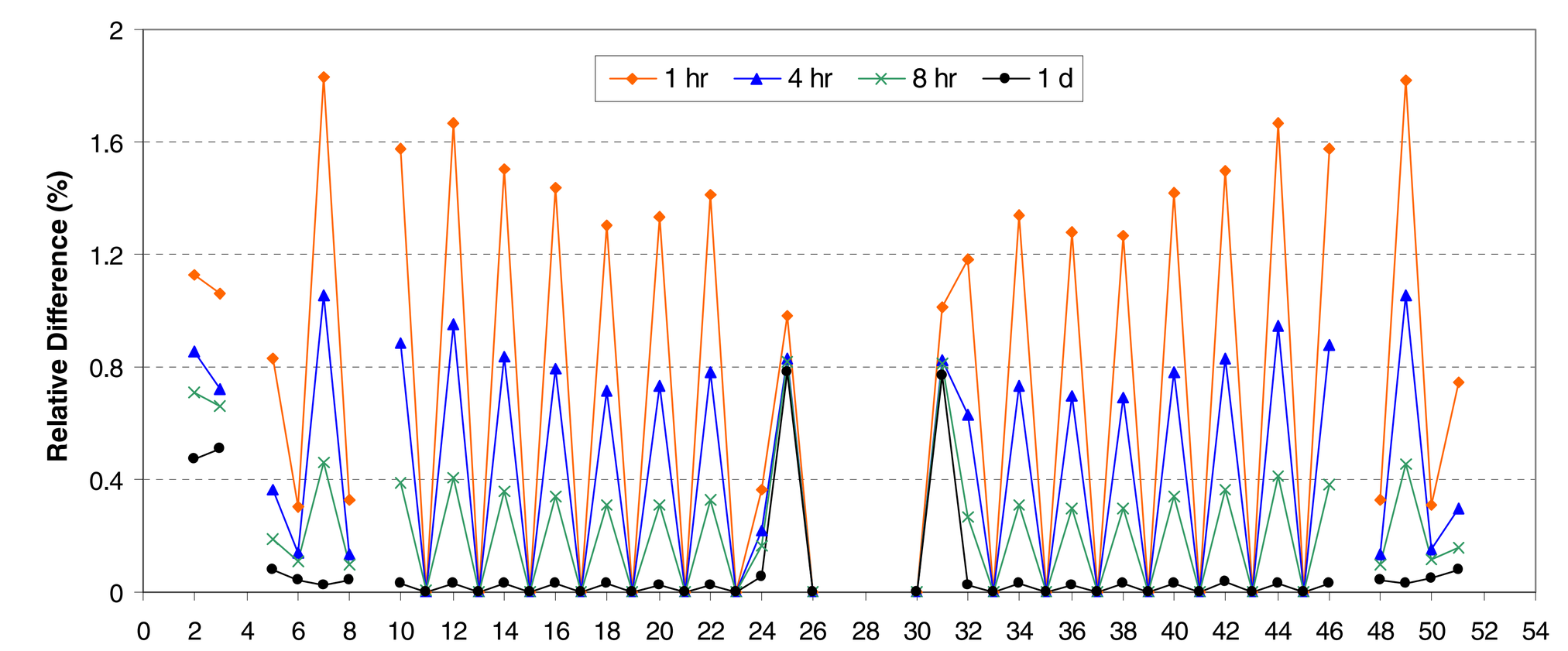
The last designed schedule (case 8) had four sub-schedules: one block of two (original) uniform pulses followed by the sub-schedules from cases 5, 6, and 7, accordingly. Each sub-schedule was separated by 1200-second delay and repeated 23625 times.

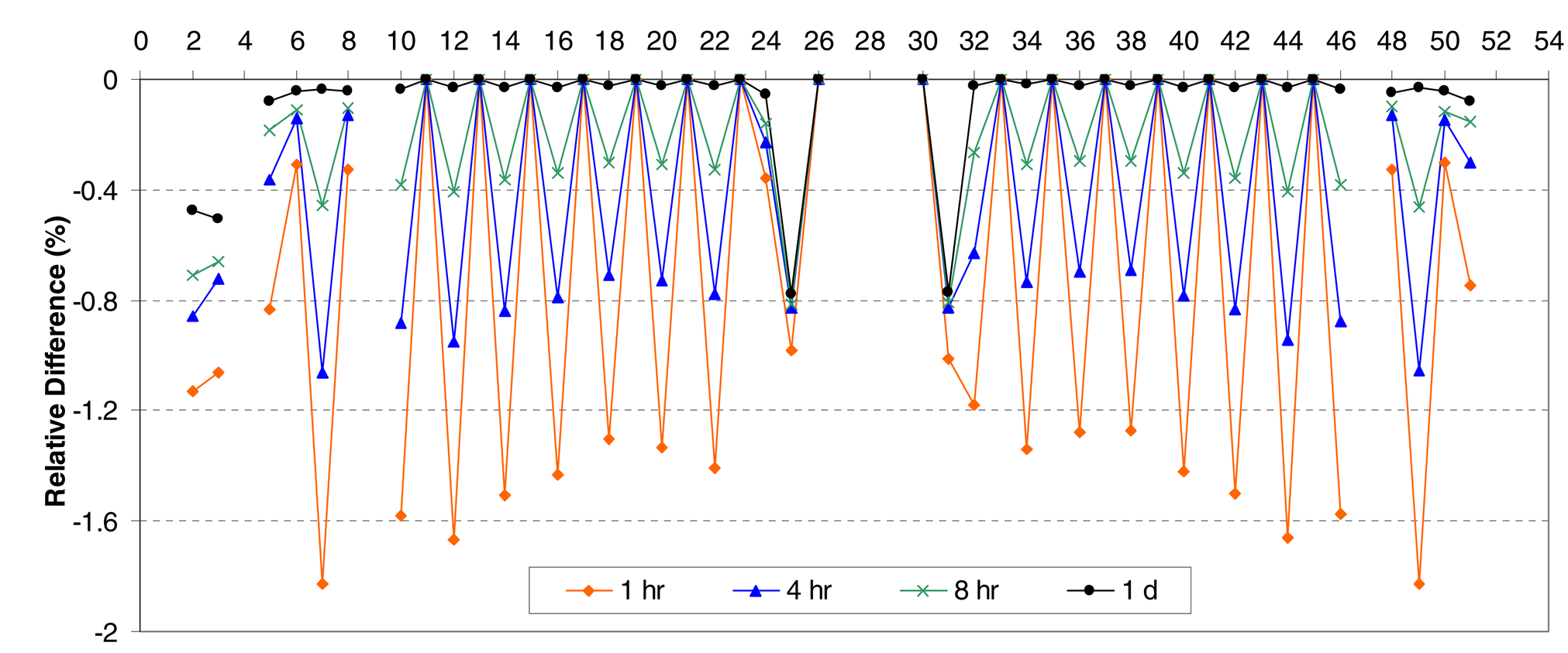
$$\text{Relative Difference (\%)} = \frac{EXACT - X}{EXACT} \cdot 100$$

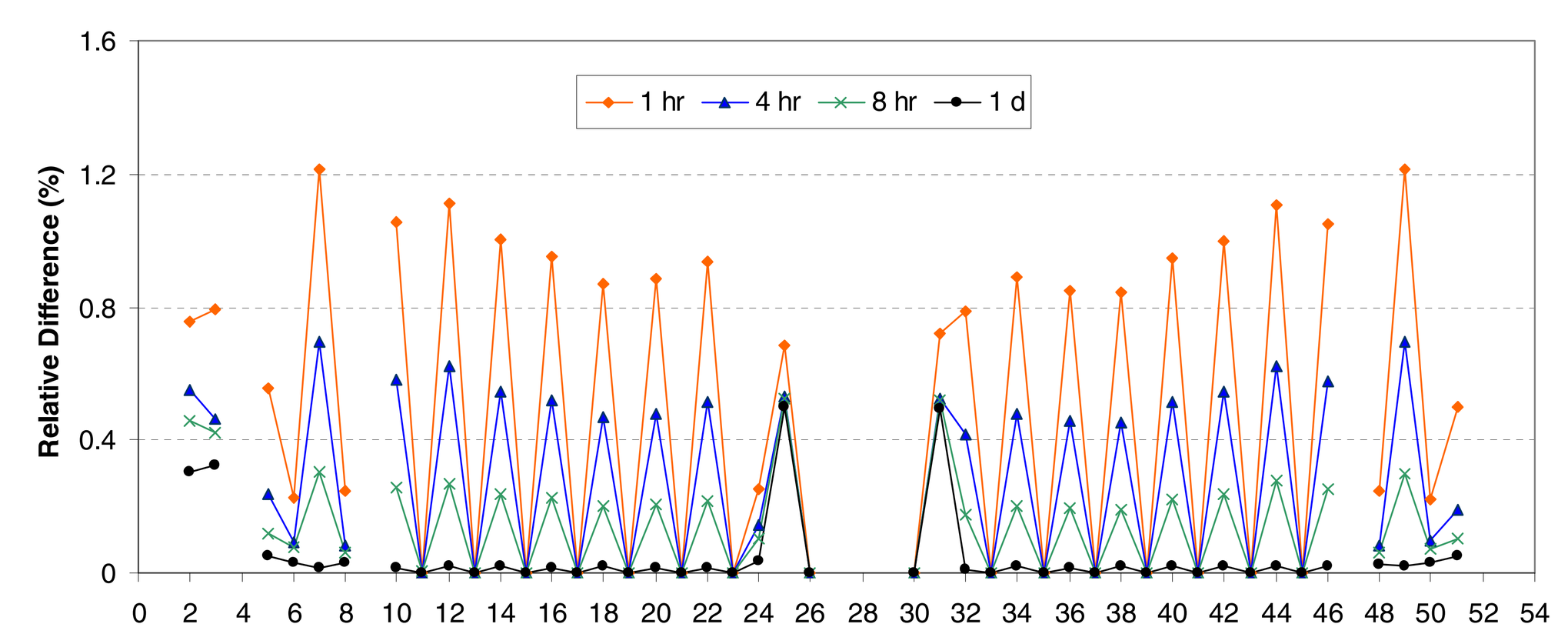
where X is a method of interest.

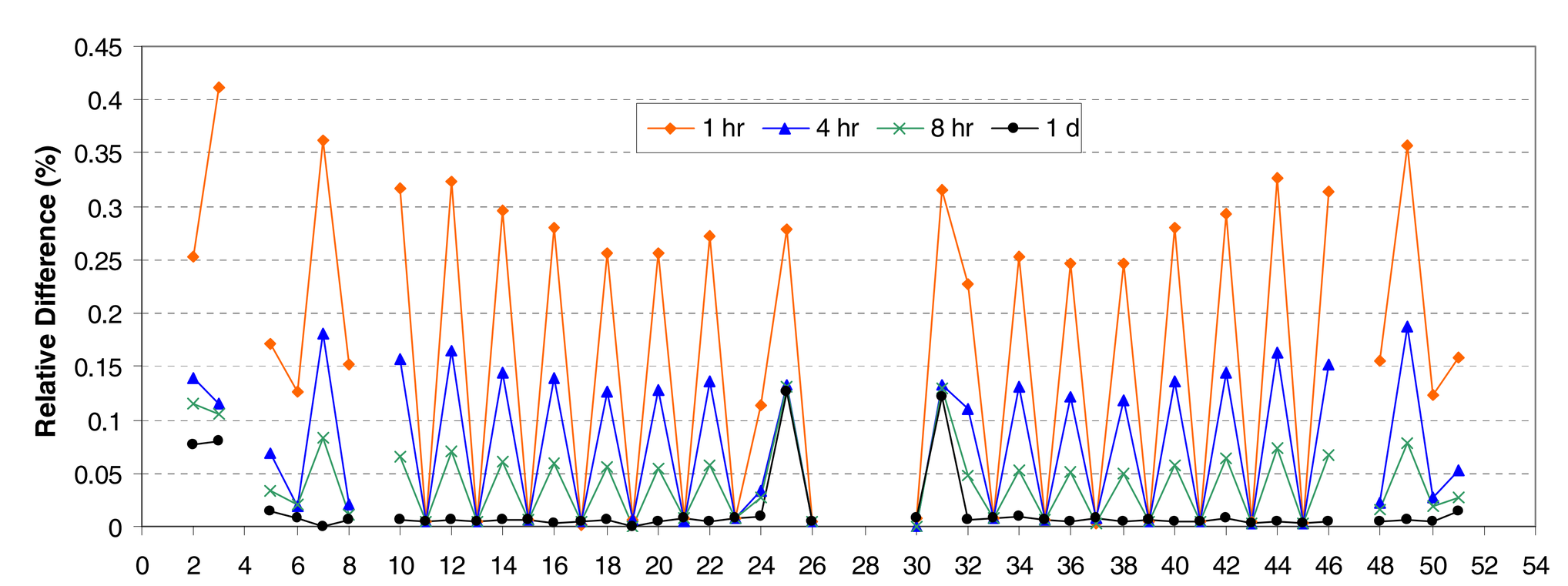












Average relative difference (%) between the results of designed schedules and exact pulsing schedule.

Designed Schedules	Cooling Time			
	1 hour	4 hours	8 hours	1 day
Schedule 1	0.78	0.46	0.25	0.095
Schedule 2	0.017	0.018	0.020	0.019
Schedule 3	0.010	0.011	0.012	0.012
Schedule 4	0.007	0.007	0.007	0.008
Schedule 5	0.74	0.42	0.23	0.077
Schedule 6	-0.74	-0.42	-0.23	-0.078
Schedule 7	0.50	0.28	0.15	0.050
Schedule 8	0.16	0.075	0.040	0.015

Discussion

As expected, the relative differences for schedule 1 monotonically decrease as cooling time increases since both the total fluence and the total operating time are conserved. The differences between the results of the exact pulsing history and the steady state approximation are negligible at long cooling times.

As for hybrid schedules, the discrepancies are reduced as the number of pulses increases. This shows that the results of the hybrid approximation more closely resemble those of the exact pulsed case as the number of pulses at the end of operation increases.

For the last four schedules, the relative differences are more noticeable at the beginning of cooling period than at one day after shutdown. Of the four schedules, schedule 8 has the least overall differences. This is due to the fact that one of every four pulses is preserved as an original uniform pulse; therefore, it more closely resembles the exact pulsing case than the other three.

Conclusion

The ALARA activation code has been validated for arbitrary irradiation schedules. The results from eight test problems have been compared to the result from the exact pulsing case. The relative differences of the results are within 1.92 percent at all zones and cooling times and continue to improve as the cooling times increase.

Based on this study, ALARA is a recommended activation code for use in a fusion power system under arbitrary irradiation schedules.

References

i. Wilson, P.P.H., *ALARA: Analytic and Laplacian Adaptive Radioactivity Analysis (PhD Thesis).* 1999, University of Wisconsin-Madison Fusion Technology Institute: Madison, WI, USA

ii. Wilson, P.P.H., et al., *Validation of the ALARA Activation Code.* Fusion Technology, 1999. **34**.

iii. Sawan, M.E., *FENDL Activation Benchmark: Specifications for the Calculational Activation Benchmark.* 1994, IAEA: Vienna.