Chapter 5 - Delayed Neutrons and the Six-Group View

Delayed Neutrons and the Six-Group View

Why less than one percent of the neutrons changes the timescale of reactor control.

What Chapter 4 left ready

Chapter 4 compared neutron creation and neutron removal as competing rates. That comparison explained subcritical, critical, and supercritical behaviour, and it showed why startup belongs naturally to a stochastic population story.

One ingredient was still missing. A real power reactor is not controlled only by prompt neutrons. A small fraction of the neutrons that matter to the chain arrives late, after unstable fission products decay. That fraction is small - roughly 0.65 percent for the representative PWR values used in this companion - but it changes the time scale of the entire control problem.

In the birth-death language, delayed neutrons are delayed births. They are not born directly at the instant of fission. They pass first through precursor populations, and those precursors release neutrons over seconds rather than over the prompt timescale. This chapter adds that delay to the stochastic bridge.

CHAPTER AIM	By the end of this chapter, the reader should understand why delayed neutrons make reactor control possible, why six precursor groups are used, and why point kinetics carries six delayed-neutron state variables instead of one anonymous delay.

Prompt births and delayed births

A prompt neutron is born essentially at the fission event. At the level of the birth-death chain, it belongs to the immediate creation side of the process. It appears quickly, participates quickly, and makes the uncontrolled prompt chain dangerously fast.

A delayed neutron has a different route. The fission event creates a radioactive precursor. The precursor waits, decays, and only then emits a neutron. The neutron is still part of the chain story, but the birth has been postponed through an intermediate population.

total delayed fraction: $\beta \approx 0.0065$
prompt fraction: $1 - \beta$

Representative PWR-order value used for the NEXUS-1 theoretical bridge.

This is the first important change from the pure one-class birth-death picture. The state can no longer be only the neutron count if the model wants to remember delayed births. It must also remember how many precursors are waiting to decay.

That memory is exactly what the deterministic point-kinetics equations later preserve. It tracks neutron density and also delayed-neutron precursor concentrations. The small fraction β therefore becomes a structural reason for extra state variables, not merely a parameter printed in a table.

fission → prompt neutrons
fission → precursor population → delayed neutrons

Prompt births enter the chain immediately; delayed births pass through precursor reservoirs first.

Why six groups?

Delayed neutrons do not all arrive with the same delay. Different fission-product families decay on different time scales. Some release neutrons after many seconds; others act much more quickly. A single delay would blur that structure, so reactor kinetics traditionally groups delayed-neutron precursors into six effective families.

The six-group view is not a claim that only six isotopes exist. It is a compact engineering representation. Each group stands for a band of precursor behaviour with its own decay constant and its own contribution to the total delayed fraction.

Group	Approx. half-life	Decay constant λ_i (s^{-1})	Yield fraction β_i	Interpretation
1	55.7 s	0.0124	0.000215	slowest memory
2	22.7 s	0.0305	0.001424	large slow contribution
3	6.22 s	0.111	0.001274	middle delay
4	2.30 s	0.301	0.002568	largest contribution
5	0.610 s	1.14	0.000748	fast delay
6	0.230 s	3.01	0.000273	very fast tail

Table 5.1 - Representative six-group delayed-neutron parameters used as the teaching basis for this volume; they are not tuned to any real plant.

The important architectural idea is that each group has a stored population. In deterministic point kinetics those populations appear as C_1 through C_6. Each receives precursors from fission and loses them by decay. When a group decays, it contributes delayed neutrons back into the neutron population.

The controllability gift

Without delayed neutrons, the chain would be governed almost entirely by the prompt timescale. That timescale is far too fast for ordinary mechanical control. The delayed fraction does not make the reactor slow in every respect, but it gives the controlled reactor a slower governing period as long as operation remains below prompt critical.

This is why a fraction that looks numerically tiny is operationally enormous. It gives control rods time to act. It gives feedback time to be felt. It lets the reactor be governed by seconds rather than by the microscopic prompt birth interval.

prompt-critical boundary, in this simplified bridge:

$$k_{eff} (1 - \beta) = 1$$

Below this boundary, delayed neutrons remain part of the governing control timescale.

In the NEXUS-1 story, this is the conceptual link between the stochastic bridge and the visible kinetics screen. The screen does not show individual source-neutron histories. It shows a deterministic state with delayed-neutron groups because, at the engineering level, those groups are the surviving memory of the stochastic process.

Delayed neutrons are therefore not a footnote. They are the reason the later point-kinetics model has its characteristic shape: one prompt neutron population coupled to six precursor reservoirs, all feeding back into the same chain.

What Chapter 5 adds to the model

Chapter 5 has added memory to the birth-death bridge. Chapter 4 could compare creation and removal as if births arrived immediately. This chapter says that a small part of creation waits inside precursor populations before returning to the chain.

That change prepares the rest of the book. The master equation can still describe a stochastic system, but the state must now include more than the neutron count if delayed births are to be represented honestly. The deterministic limit will carry the same fact in a more compact form: neutron density plus six precursor concentrations.

The reader should now have the minimum conceptual equipment needed for the point-kinetics bridge: prompt births, delayed births, total delayed fraction β, six precursor groups, decay constants λ_i, and group yields β_i. The next step is to show how those pieces become equations.

neutron population N
precursor groups $C_1, C_2, C_3, C_4, C_5, C_6$

The state variables that Chapter 6 will connect to the point-kinetics equations.

HONEST BOUNDARY

The six-group values in this chapter are representative textbook-order values used for explanation and for the NEXUS-1 demonstrator bridge. They are not a licensed data set, not a plant-specific calibration, and not a safety case.