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14 NORMAL OPERATING LIMITS

Learning Objectives:

1. Define the following terms:
   a. Axial shape index (ASI)
   b. Equilibrium shape index (ESI)
2. Briefly describe the reasons for limiting power escalation rates.
3. Explain why load changes via soluble poison are preferred over load changes with CEA motion.
4. Briefly explain how fuel assembly waterlogging results in increased reactor coolant system (RCS) activity.

14.1 Introduction

The purpose of this chapter is to describe some of the normal operational limitations that the plant staff must deal with on a day-to-day basis. Examples of these limitations are power escalation limits and axial flux shape control.

14.2 Axial Shape Index

ASI is defined as the power generated in the lower half of the core less the power in the upper half of the core divided by the sum of these powers.

$ASI = P_B - P_T / P_B + P_T$

where:

P_B = power in the lower half

P_T = power in the upper half

Negative values of ASI indicate that power is peaked in the top of the core while positive values indicate that power is peaked in the bottom of the core.

ASI is calculated by the core operating limits supervisory system (COLSS) and the core protection calculators (CPCs). The COLSS program receives inputs from each of the incore detector assemblies. Basically, the values from each of the five neutron detectors per assembly are connected by a curve fit program. Next, power is calculated at forty points (nodes) on the curve. The computer then generates an ASI value by:

$$ASI = \frac{Power\ in\ the\ lower\ 20\ nodes - Power\ in\ the\ upper\ 20\ nodes}{Power\ in\ all\ 40\ nodes}$$

The CPCs perform a similar calculation. However, the CPCs receive only three input values. One value from each of the three fission chambers that make up a linear power channel.

A term that is related to ASI is ESI. ESI is defined as the value of ASI that would exist at 100% power, equilibrium xenon, and all CEAs withdrawn. In other words, ESI is the natural axial flux profile of the reactor.

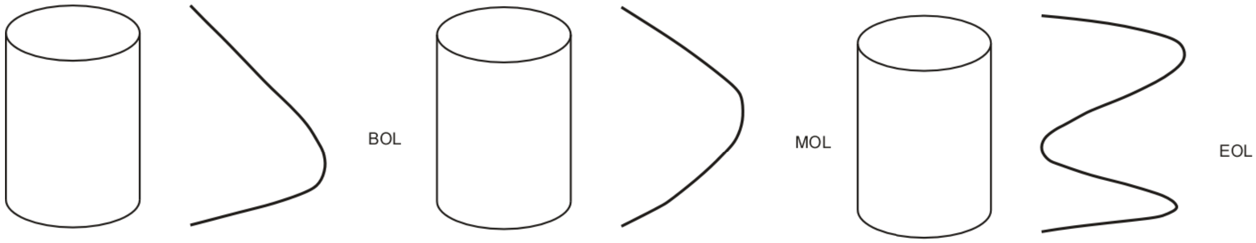

Figure 14-1 Axial Flux Profile vs. Core Age

The natural axial flux profile is time in core life dependent (Figure 14-1). With a new core, flux tends to be peaked in the bottom of the core because of the negative moderator temperature coefficient and the fresh fuel. As the core ages, the bottom flux peak depletes the fuel in this region, and the flux profile shifts upward. At middle of life conditions, the axial profile is almost a perfect cosine wave. With power peaked in the center of the core, the fuel in this area will be depleted. Therefore, the end of life condition will be saddle shaped with a flux peak in the top of the core and a smaller peak in the bottom of the core.

Since flux profiles change over core life, ESI also changes. It is Combustion Engineering's recommendation that ESI be determined by the nuclear engineering department at least monthly.

Large and rapid changes in axial flux may lead to fuel cladding defects. Of course, cladding defects increase RCS activity.

14.3 Axial Xenon Oscillations

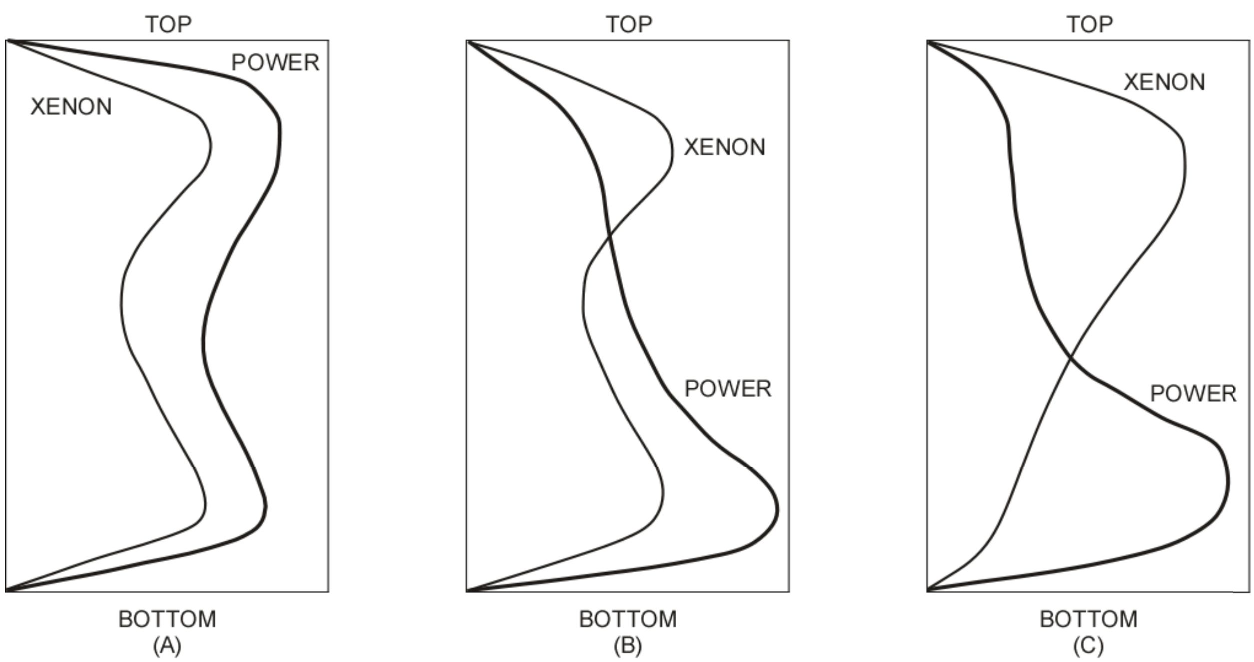

Figure 14-2 Axial Xenon Oscillation

Axial xenon oscillations can and do occur in commercial pressurized water reactors. To illustrate how such an oscillation is started, assume that the xenon and power shapes shown in Figure 14-2(a) exist. Now assume that the CEAs are deeply inserted, shifting flux to the bottom of the core (Figure 14-2b). Since flux has been reduced in the top of the core, the burnout of xenon is also reduced. The decay of iodine (I-135) to xenon

causes an increase in the xenon concentration (Figure 14-2c). This increase in poison in the top of the core results in a further decrease in power (flux) in the top of core. Also, the increase in power in the bottom of the core increases xenon burnout in this area. This reduction in poison allows flux to increase in the bottom of the core. The increase in power in the bottom of the core is also shown in Figure 14-2c.

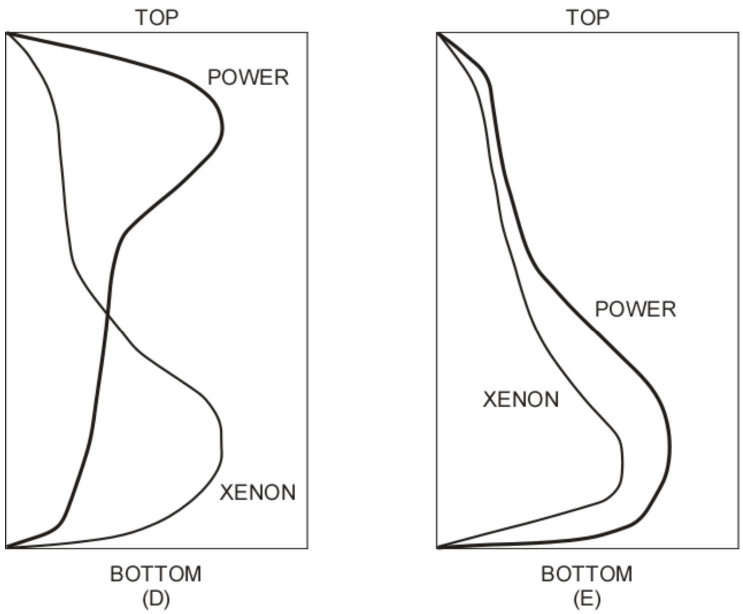

Figure 14-2 Axial Xenon Oscillation

As time passes, the increase in power in the bottom of the core produces more iodine which, in turn, decays to xenon. With more poison in the bottom of the core, neutron power is reduced. Also, with very little power in the top of the core, the decay of xenon reduces its effect on flux. So, power begins to increase in the top of the core. These effects are illustrated in Figure 14-2d. It should be noted that these oscillations have a period of approximately 30 hours.

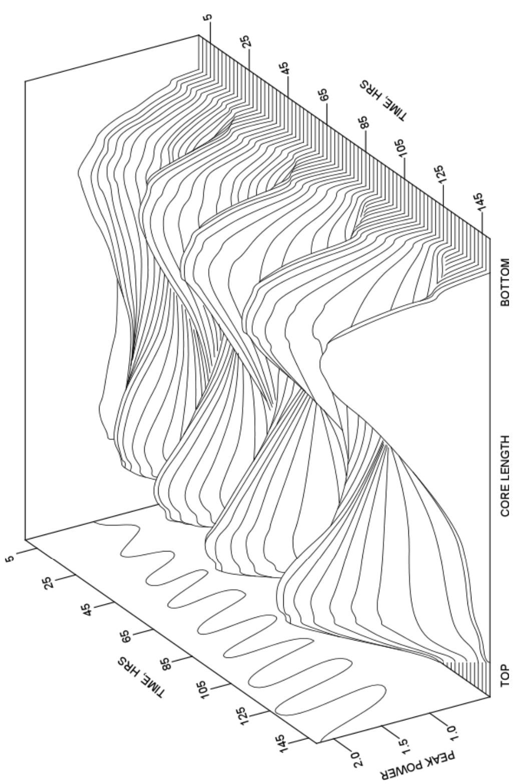

Figure 14-3 Divergent Axial Xenon Oscillation

The oscillations in xenon and power may be convergent (Figure 14-2e) or divergent (Figure 14-3). Divergent oscillations tend to occur later in core life. Two control schemes are available to dampen the xenon oscillation.

The first scheme utilizes the last regulating group to dampen the oscillation as the core ASI becomes more negative (top-peaked power). Usually, these CEAs are fully withdrawn from the core. As ASI starts to deviate from the ESI value, Group 6 CEAs are diluted into the core. The insertion of the CEAs should bring the ASI to within allowable limits. This action is called half wave dampening because the action takes place on the negative part of the cycle. When the ASI becomes positive, the CEAs are borated to the all rods out (ARO) condition.

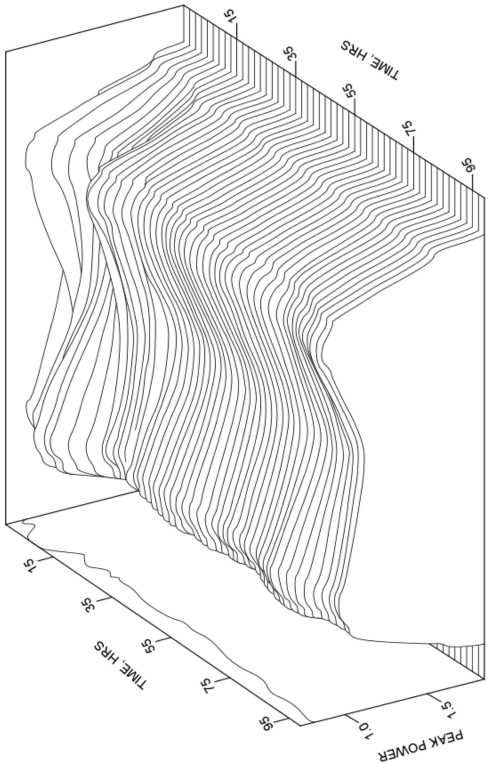

Figure 14-4 Dampened Xenon Oscillation

The second method of xenon oscillation control is called full wave dampening and involves the manipulation of the part length CEAs (PLCEA). In this control scheme, the poison section of the PLCEAs is positioned toward the top of the core as ASI becomes negative and toward the bottom of the core when ASI becomes positive. Figure 14-4 shows the effect of dampening.

Regardless of the control scheme that is used, ASI can usually be maintained within .05 units of the ESI value.

14.4 Temperature Induced Flux Shape Changes

In the previous section axial flux shape changes were induced by CEA motion. However, axial flux changes can also be caused by a change in temperatures in the core. These changes are easily illustrated by assuming that the plant is at 100% power with an ASI of zero and all CEAs fully withdrawn.

Now suppose that power is reduced from 100% to 50% by boration. As load is decreased, both the hot leg (T_h) and cold leg (T_c) temperatures change. But the change in T_h is much greater. In this example, T_h will decrease from 612°F to 579°F, while T_c will decrease from 553°F to 549°F. The top portion of the core experiences a reactivity addition associated with a 33°F temperature change, while the bottom of the core sees a reactivity change associated with a 4°F change. If the moderator temperature coefficient is negative, then a larger amount of positive reactivity will be added to the top of the core. In this example, ASI will assume negative values as power is decreased.

If power is slowly changed, then the changes in flux shape will occur slowly. A slower rate of change of axial flux shape results in a slower rate of change of local linear heat rate.

14.5 CEA Motion

In addition to changing power with soluble poison, the CEAs can also be used to maneuver the plant. However, the movement of CEAs can drastically change axial flux shape and local heat rates. Imagine that a CEA is partially inserted into the core with flux peaked below the tips of the CEA fingers. When the CEA is withdrawn, the reaction rate in the area adjacent to the CEAs previous location increases. The increase in reaction rate raises flux in this location and causes an immediate change in fuel temperature.

14.6 Fuel Defects

A fuel defect is defined as any degradation of cladding integrity that will allow fission products to escape into the coolant.

There are four principle mechanisms which are known to cause cladding defects:

1. Hydriding,
2. Fretting,
3. Weld defects and
4. Pellet to cladding interaction.

Hydriding occurs when too much moisture is present during fuel pellet or fuel rod construction. When the fuel is heated during power operation, the water leaches from the pellet. A zirconium-water reaction takes place which results in free hydrogen. The free hydrogen attacks the cladding internally resulting in a pit hole failure.

Fretting occurs when the fuel rods are not held firmly in the fuel assembly. As flow passes around the rods, the rods move on the inside of the spacer grid. Over a period of time, the rod motion will wear a hole in the cladding.

Weld defects occur in the weld area near the fuel rod end caps. These defects result in a porous region which is susceptible to further damage due to its inferior strength.

These first three failure mechanisms can be avoided if care is exercised in the design, manufacture, and quality control of the fuel assemblies. These items are the responsibility of the fuel supplier.

The fourth failure mechanism, pellet to cladding interaction (PCI), has been the most significant cause of cladding defects.

Pellet to cladding interaction is caused by rapid changes in local heat rates. If power is changed rapidly, large local fuel temperature changes can occur. As the fuel rod heats up, the fuel pellets expand faster (and to a greater magnitude) than the cladding. This places stress on the cladding. At the same time as the pellets expand, fission product gasses trapped near the surface of the pellet escape. These gases attack the cladding resulting in corrosion of the cladding. These two effects taking place together result in a high likelihood of fuel defects.

The two effects described above occur with linear heat rates in excess of 12.5 kW/ft. The normal linear heat rate averages five to 5 1/2 kW/ft with a maximum of 10.5 kW/ft in high burnup areas. If high linear heat rates can be avoided, then cladding integrity can be maintained.

14.7 Fuel Preconditioning Limits

The purpose of fuel preconditioning limits is to eliminate local overshoots in power which, if left uncontrolled, would result in large numbers of fuel rods exceeding their desired linear heat rate.

Using a graph of kW/ft versus power, the above guidelines may be translated into percent power. These power limits are easier for the operator to use. category 1 limits are 3%/hr, category 2 limits are 20%/hr and category 3 limits are 30%/hr.

In addition to the power escalation limits, ASI should be controlled to minimize local heat rate changes. The recommended control ranges are:

Table 14-1 Fuel Preconditioning Guidelines (applicable above 50% power)

Category	Applicable Range Maximum of Local Power Density	Rate of Change
1. Increase in LPD to a level that has not been sustained for more than 3 hrs. in the last 60 days.	>5 kW/ft	0.3 kW/ft/hr
2. Increase in LPD to a level which has not been sustained for 3 hrs. within the last 8 days.	>5 kW/ft	2 kW/ft/hr
3. Increase in LPD to a level which has been sustained for 3 hrs. within the last 8 days.	>5 kW/ft	3 kW/ft/hr

1. Maintain ASI within .01 units of ESI when changing power level and
2. Maintain ASI within .05 units of ESI when operating at steady state conditions.

The second limit allows control of axial xenon changes which occur slowly.

The final guideline (or limit) involves the removal of the CEA fast withdrawal feature from the RRS. This prevents rapid CEA motion and the associated rapid change in fuel temperature

14.8 Waterlogged Fuel Assemblies

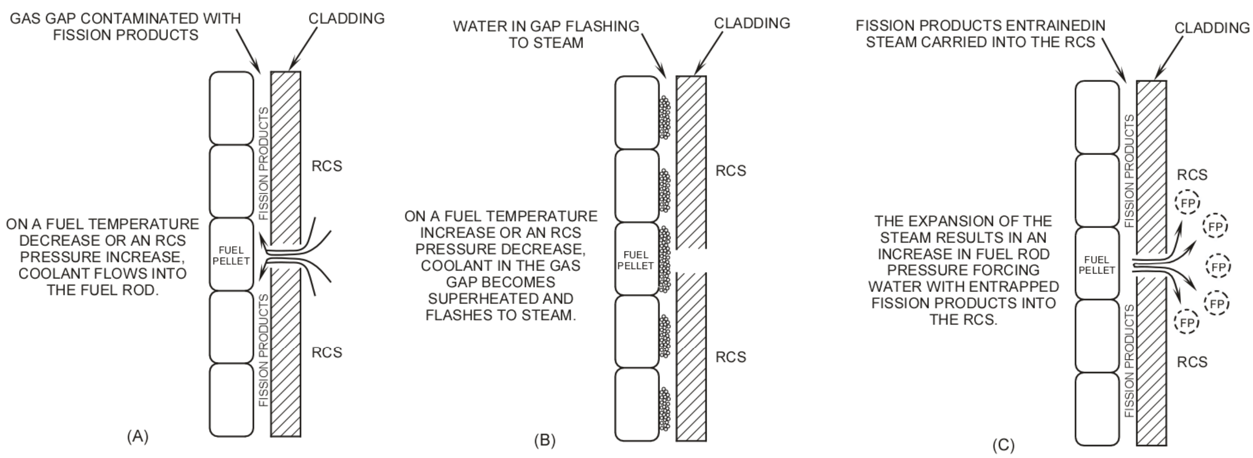

Figure 14-5 Waterlogged Fuel Assemblies

In addition to minimizing the possibility of PCI, the fuel preconditioning guidelines should help reduce the RCS activity associated with waterlogged fuel assemblies.

A waterlogged fuel assembly is an assembly that contains defective fuel rods which are filled with reactor coolant. The rods become filled with coolant when the internal pin pressure is lost and RCS pressure forces coolant into the fuel rod (Figure 14-5A).

As power is increased, fuel temperature increases. When the fuel temperature is at saturation temperature for the existing RCS pressure, the water in the fuel rod starts to flash to steam (Figure 14-5B). The expansion of the steam forces coolant and fission products into the RCS (Figure 14-5C).

If power is rapidly escalated, then steam is formed at a faster rate. Since the defect is small, the relief path for the steam is restricted. Therefore, steam pressure can increase. The increased pressure forces more fission products into the coolant and can expand the size of the defect.

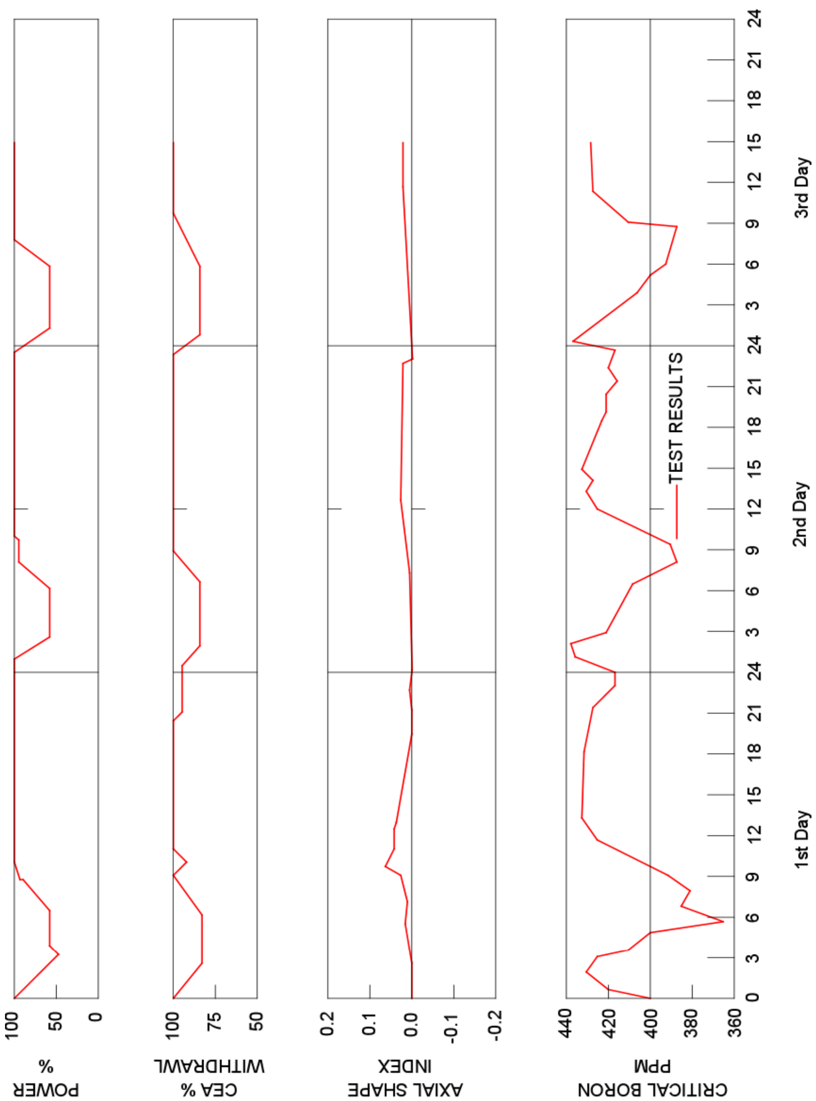

Figure 14-6 Load Following

14.9 Load Following Capabilities

Although most nuclear units are base loaded load following tests, under the fuel preconditioning limits, have been conducted. A weekend load reduction to fifty percent is shown in Figure 14-6. The load changes were conducted with soluble poison control while CEA position was changed in response to changes in ASI.

14.10 Summary

Axial shape index and power escalation limits are two normal operating limits that are maintained by the operating staff. These limits are imposed to maintain fuel cladding integrity.

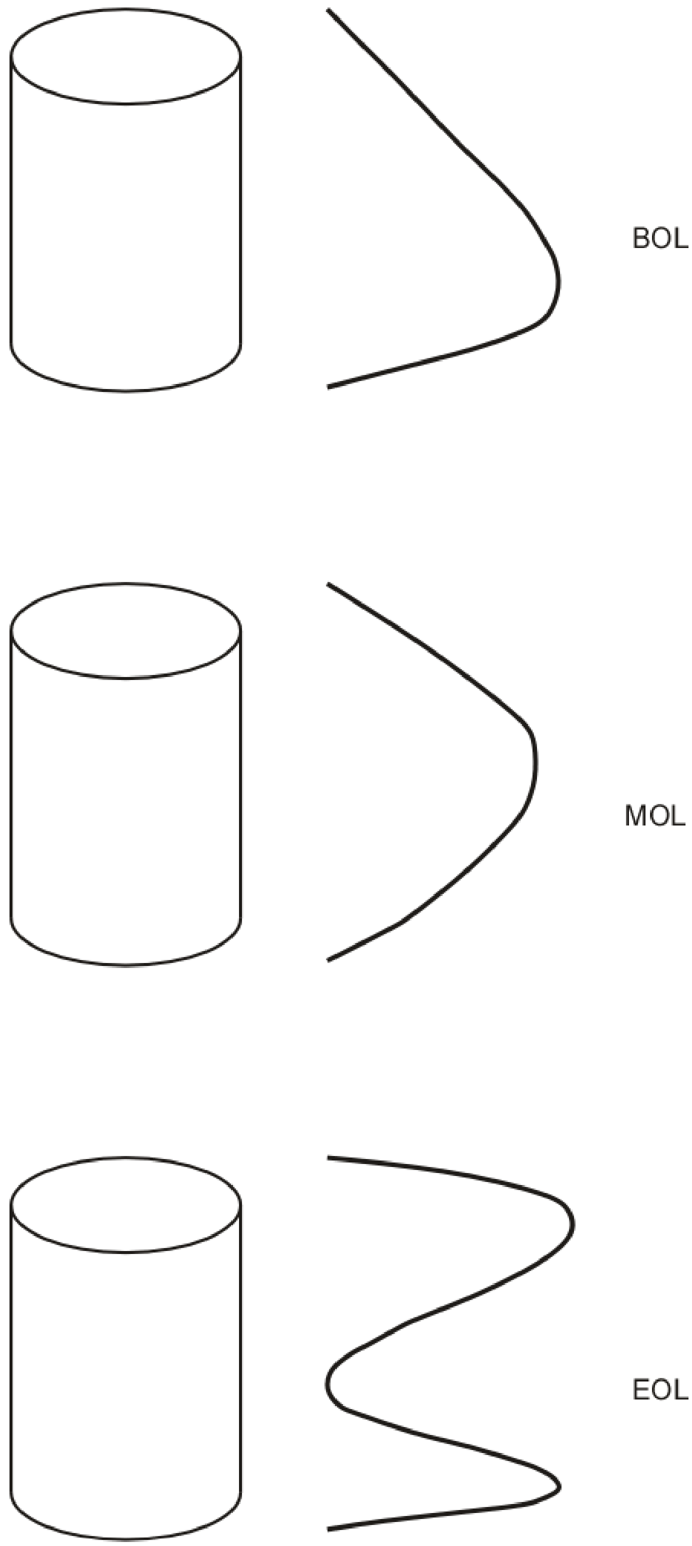

Figure 14-1 Axial Flux Profile vs. Core Age

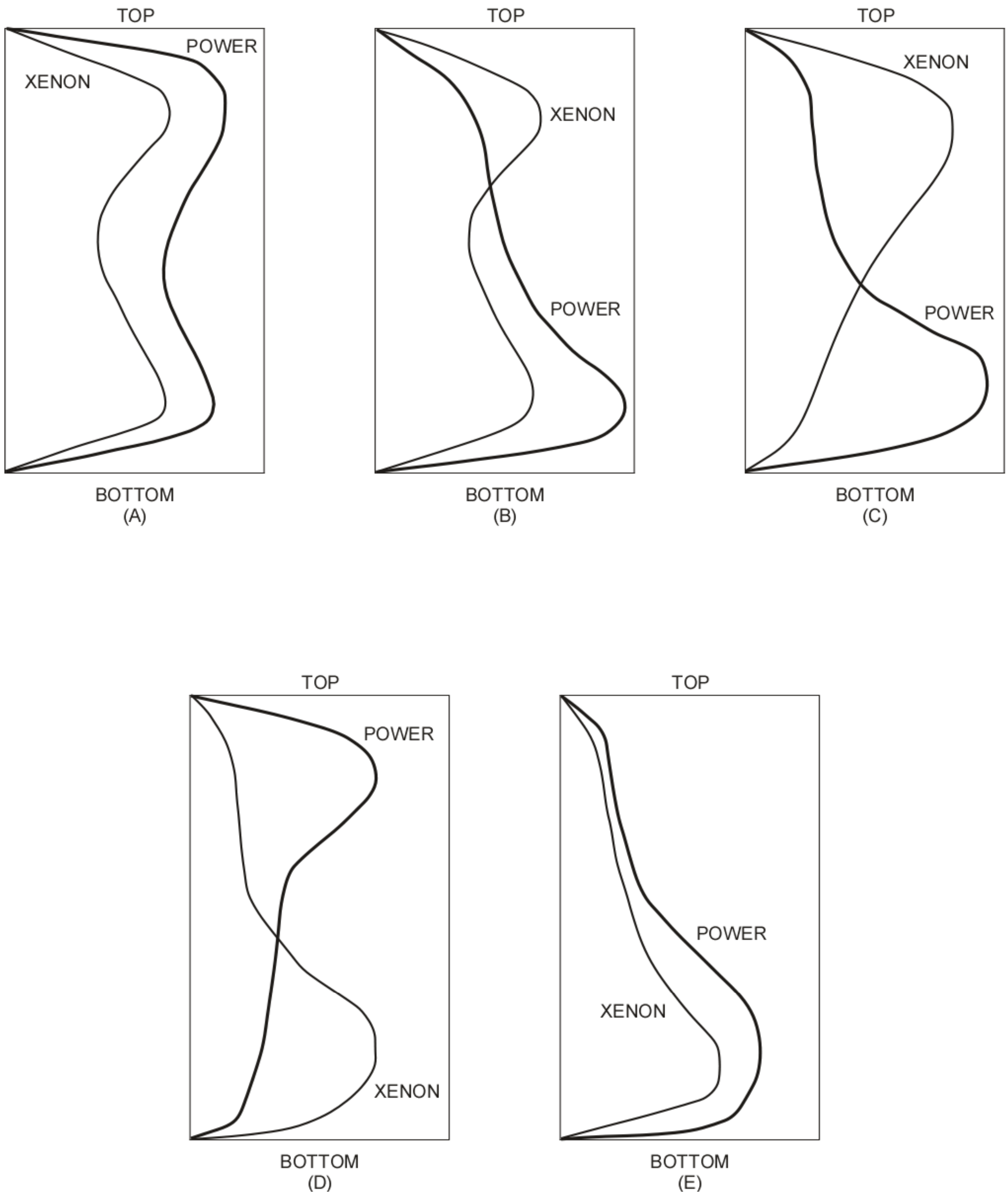

Figure 14-2 Axial Xenon Oscillation

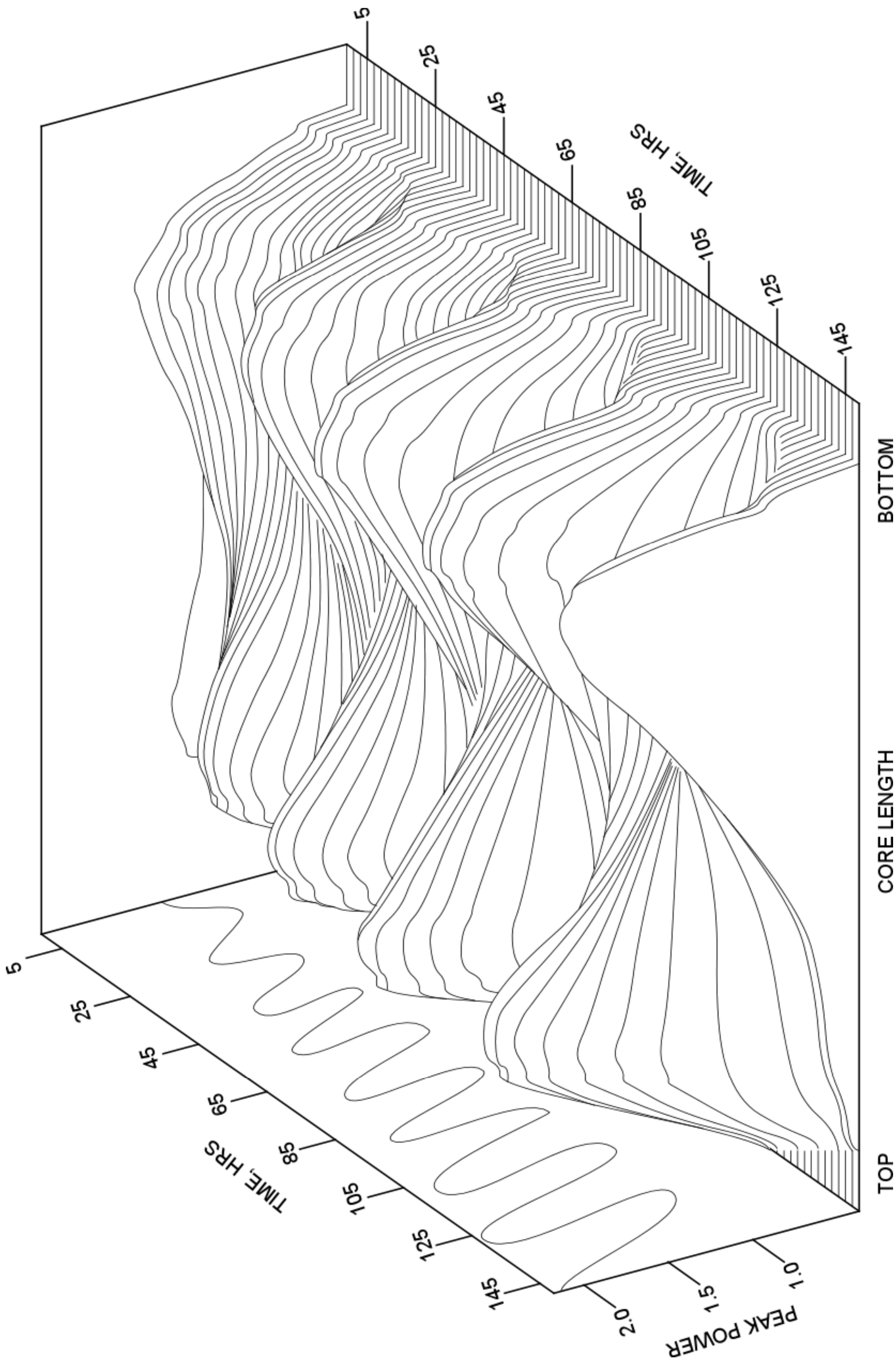

Figure 14-3 Divergent Xenon Oscillation

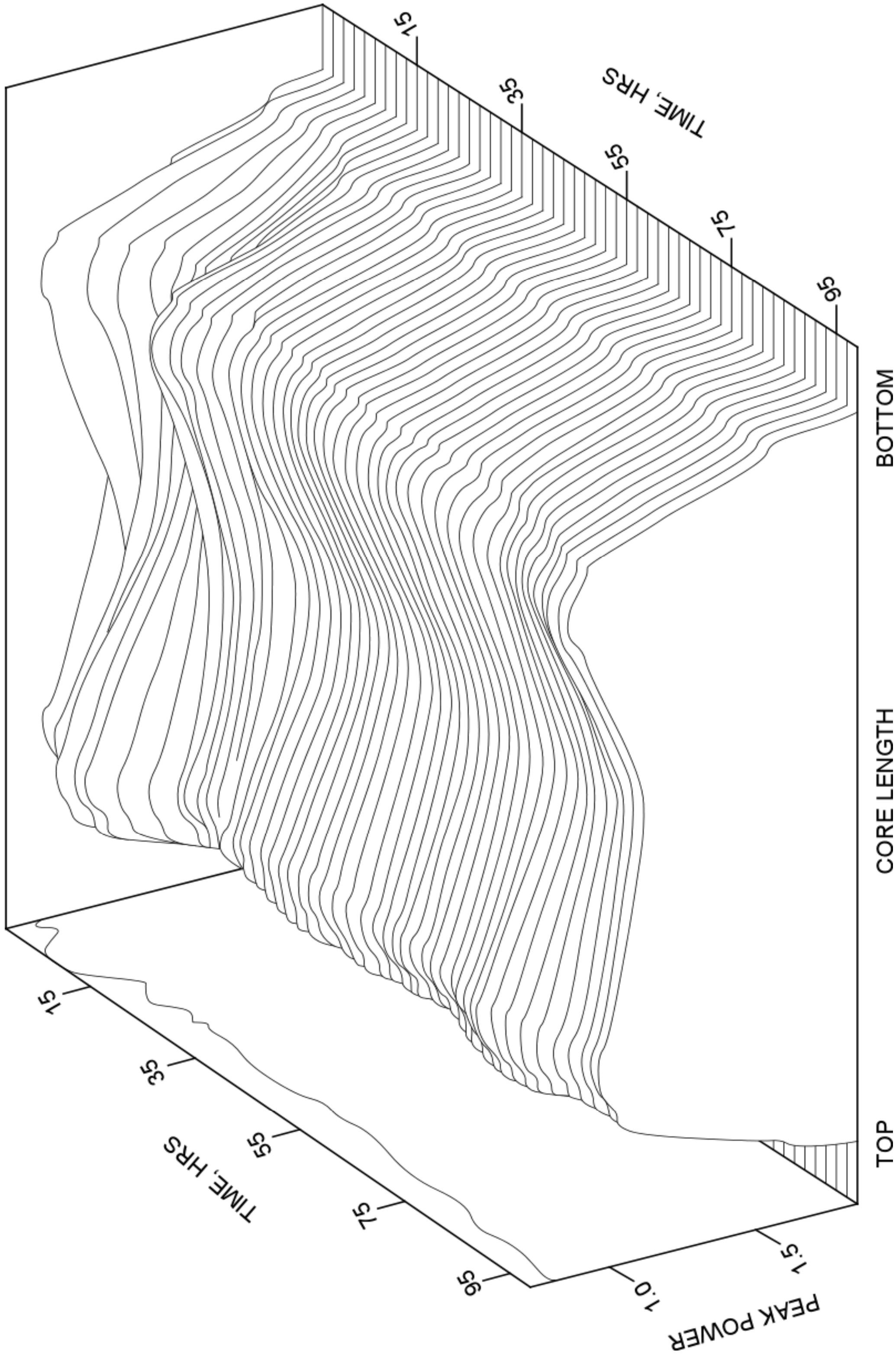

Figure 14-4 Dampened Xenon Oscillation

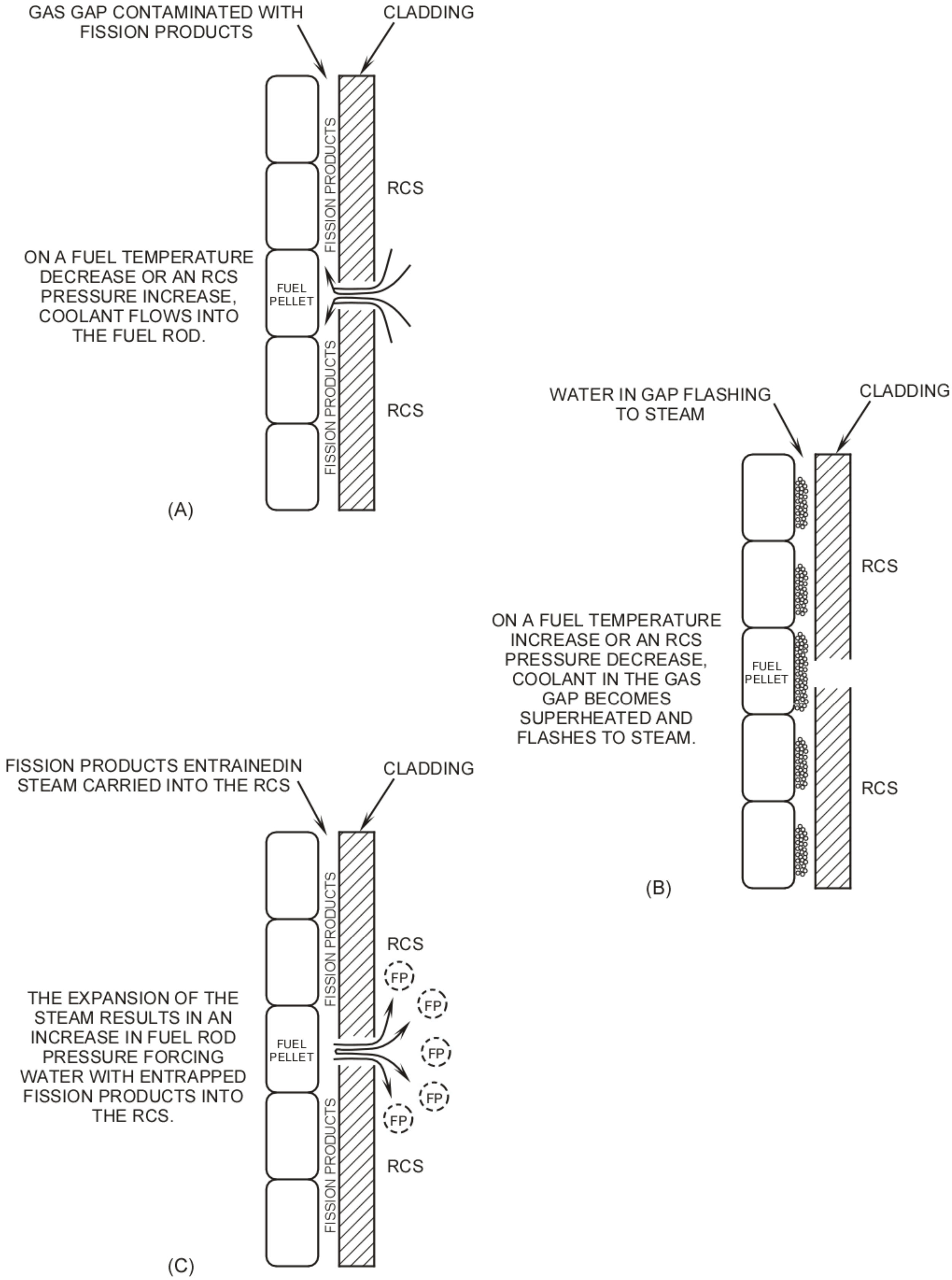

Figure 14-5 Waterlogged Fuel Assemblies

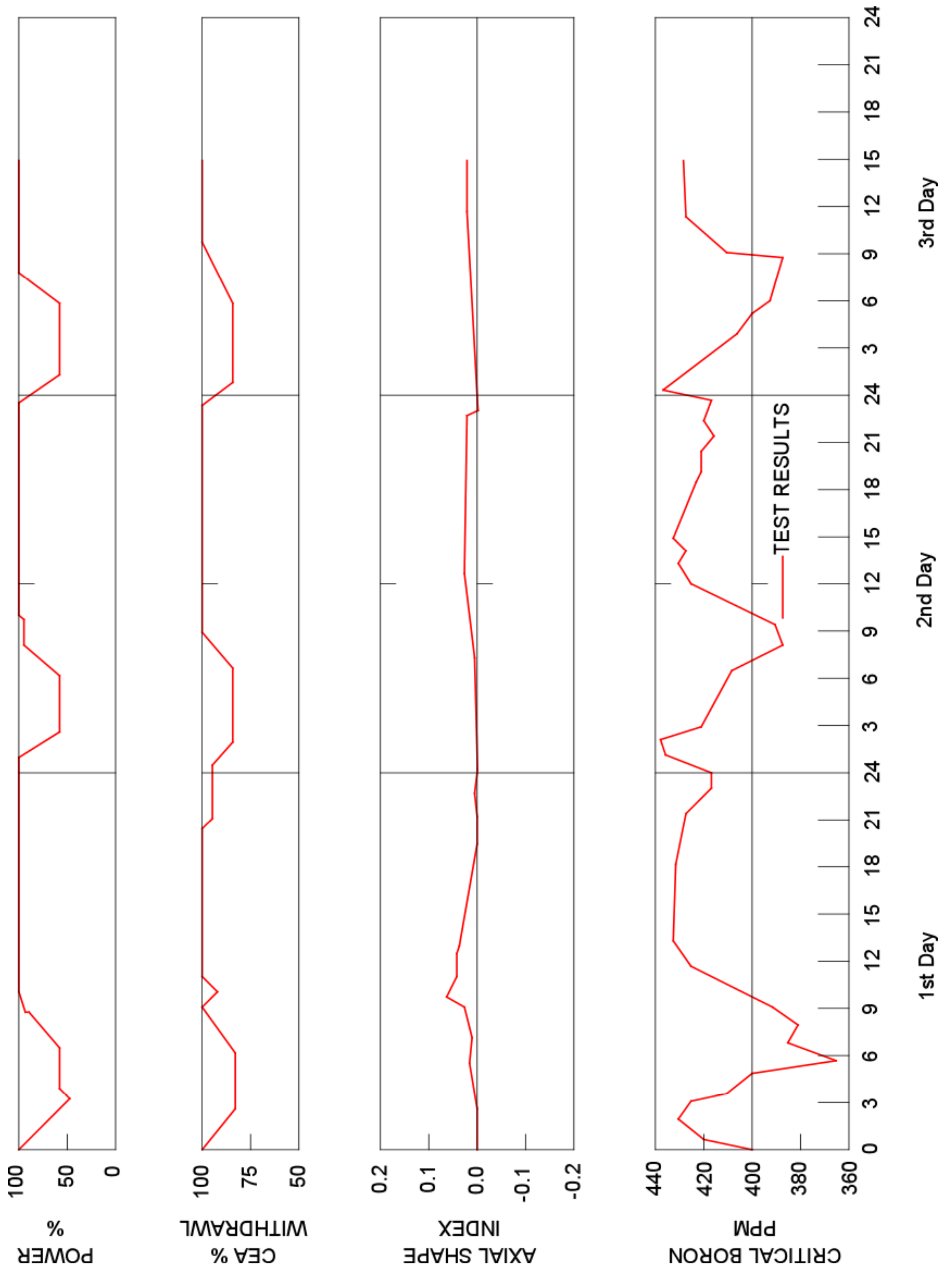

Figure 14-6 Load Following