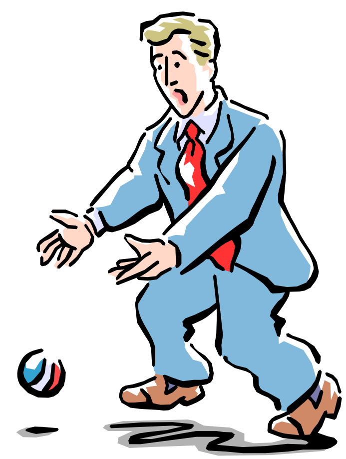
V.C. Summer
Inadvertent Criticality

Section 7.2



Learning Objectives

- Briefly discuss the V.C. Summer startup accident.
- Explain the causes of the accident.
- Explain the safety implications of the accident.
- Explain what procedural limitations and administrative controls <u>should</u> have prevented this accident.

Background

- 3-loop W plant in South Carolina.
- Commercial operation began 1982.
- In Feb. 1985, the plant had been operating intermittently.
- 2/28/85, during a startup, the Rx tripped due to unexpected criticality.

Summary of Event (Section 7.2.1)

- The plant had been operating intermittently during the previous month.
- ECP was 168 steps on control bank D.
- Non-licensed trainee performing S/U under supervision of SRO licensed shift supervisor (SS).
- SS directed trainee to w/draw rods to 100 steps on control bank D.

Summary of Event (continued – 1)

- The trainee only watched rod positions while withdrawing control banks.
- When power reached P-6, SS blocked SR high flux trip.
- Rx tripped w/ CB-D @ 76 steps.
- Rx tripped on high positive flux rate.
- When Rx tripped, power was ~ 6%.
- 16 – 17 dpm Startup rate (SUR).

Causes (Section 7.2.2)

- Failure to Follow Procedures.
- Incorrect Calculation of the Estimated Critical Rod Position (ECRP).
- Inadequate Training / Experience Level of Trainee.
- Inadequate Supervision of Trainee by Shift Supervisor (an SRO).

Failure to Follow Procedures

- Licensed Operator (the SS) responsible for the S/U failed to monitor excore NIs for indications of criticality when positive reactivity was being added (as required by procedures).
- The SS blocked the SR reactor trip when P-6 permissive was received w/o noticing the rate at which power was increasing.

Incorrect Calculation of the ECP

- The calculation (power block method) for predicting Xe and Sm reactivity worth can produce significant errors when the Rx had recently been operating at widely varying power levels. Rx had been critical 3 hours before S/U.

Xe

Sm

The calculation used MOL Rod Worth Curves rather than BOL curves. The licensee's procedure lacked guidance regarding when to change to the MOL Rod Worth Curves.

Inadequate Training / Experience Level of Trainee.

- Trainee had no prior plant or simulator startup experience.
- Trainee did not know the indications for a critical Rx. Critical

Trainee did not know that procedures required the excore NIs should be monitored for indications of criticality any time positive reactivity is being added to the core.

Inadequate Supervision of Trainee

- SS was responsible for:
  - the Rx S/U (bringing the Rx critical),
  - the startup activities for the entire control room staff as well as S/U activities, and
  - supervision of trainee.

Consequences

- Rx tripped w/ CB D @ 76 steps.
- Rx tripped on high positive flux rate.
- When Rx tripped, power was ~ 6%.
- 16 – 17 dpm SUR.
- Rx was critical w/ CB D @ ~ 40 steps.
- No fuel damage.

Safety Implications (Section 7.2.3)

- Uncontrolled rod withdrawal while subcritical was an analyzed event in FSAR.
- FSAR assumed reactivity addition rate of 105 pcm/sec. Actual was 10 pcm/sec.
- FSAR assumed trip on high flux low setpoint (35% @ Summer) rather that high positive flux rate.

Safety Implications (Continued)

- No fuel or cladding damage.
- DNBR remained above limit.
- Rods were > RIL when critical.

Procedural Limitations & Administrative Controls that Should Have Prevented the Inadvertent Criticality.

- Operators monitoring excore NIs for indications of criticality when positive reactivity was being added.
- Operators anticipating criticality whenever positive reactivity is being added.

Procedural Limitations & Administrative Controls that <u>Should</u> Have Prevented the Inadvertent Criticality. (cont-1)

- Proper supervision of trainee by licensed operators.
- Adequate training / experience of trainee prior to performing tasks.

Procedural Limitations & Administrative Controls that Should Have Prevented the Inadvertent Criticality (cont-2)

- Procedural guidance stating that the accuracy of the ECRP calculation is limited when the Rx had recently been operating at widely varying power levels.
- Procedural guidance for changing to MOL rod worth curves from BOL curves.

Corrective Actions

- Procedural inadequacies addressed.
- Inverse multiplication plots used for subsequent startups
  - to predict criticality
  - to verify accuracy of ECP.
- A quick review of inverse multiplication plots.

Subcritical Reactor

- The equation for Keff does not account for source neutrons because the number of neutrons are insignificant when compared to the number of fission neutrons in a critical reactor.

$$K_{effective} = \frac{\#\ of\ neutrons\ in\ this\ generation}{\#\ of\ neutrons\ in\ the\ previous\ generation}$$

$$K_{eff} = \frac{N}{N_0}$$

Subcritical Multiplication

- Definition: the increase in neutron population in a subcritical reactor.
  - The population increase is caused by the addition of positive reactivity.
    - Adding fuel during refueling evolutions.
    - Withdrawal of control rods
    - Boron concentration dilution.

Equilibrium Neutron Level in a Subcritical Reactor

$$CR = \frac{S}{(1 - K_{eff})}$$

- CR: Count Rate (total neutron level in counts per second).
- S: source neutron level in counts per second.
- Keff must be < 1.

Subcritical Multiplication Factor

- If we add positive reactivity, Keff gets closer to 1 and Rx is closer to being critical.

$$CR_1 = \frac{S_1}{(1 - K_{eff\,1})} \rightarrow S_1 = CR_1(1 - K_{eff\,1})$$

$$CR_2 = \frac{S_2}{(1 - K_{eff\,2})} \rightarrow S_2 = CR_2(1 - K_{eff\,2})$$

$$But, S_1 = S_2$$

A Little Algebra

$$CR_1 = \frac{S_1}{(1 - K_{eff\,1})} \rightarrow S_1 = CR_1(1 - K_{eff\,1})$$

$$CR_2 = \frac{S_2}{(1 - K_{eff\,2})} \rightarrow S_2 = CR_2(1 - K_{eff\,2})$$

$$But, S_1 = S_2$$

$$So,$$

$$CR_1(1 - K_{eff\,1}) = CR_2(1 - K_{eff\,2})$$

$$or$$

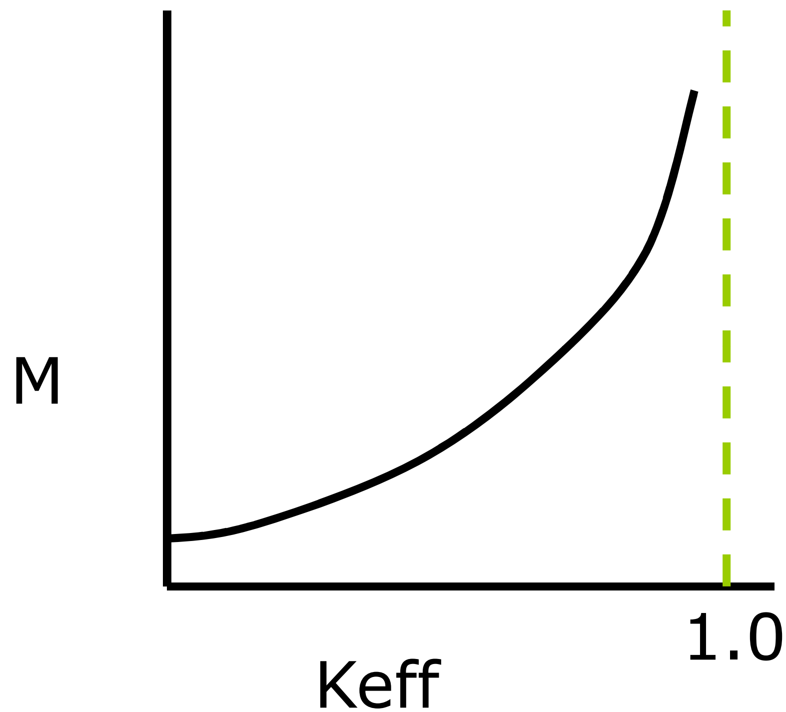
$$\frac{CR_2}{CR_1} = \frac{(1 - K_{eff\,1})}{(1 - K_{eff\,2})}$$

Subcritical Multiplication Factor (M)

$$M = \frac{(1 - K_{eff\,1})}{(1 - K_{eff\,2})}$$

$$M = \frac{CR_2}{CR_1}$$

Plots

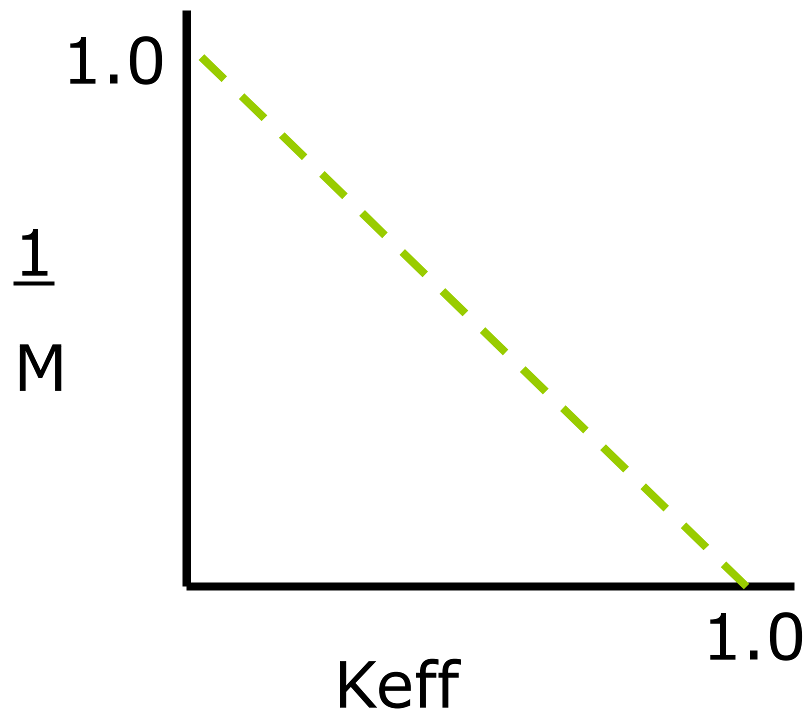


$$M = \frac{(1 - K_{eff\,1})}{(1 - K_{eff\,2})}$$

$$M = \frac{CR_2}{CR_1}$$

As + reactivity is added, Keff $_2$ approaches 1.
M approaches infinity. Can not plot it.

Plots (continued)



$$M = \frac{(1 - K_{eff\,1})}{(1 - K_{eff\,2})}$$

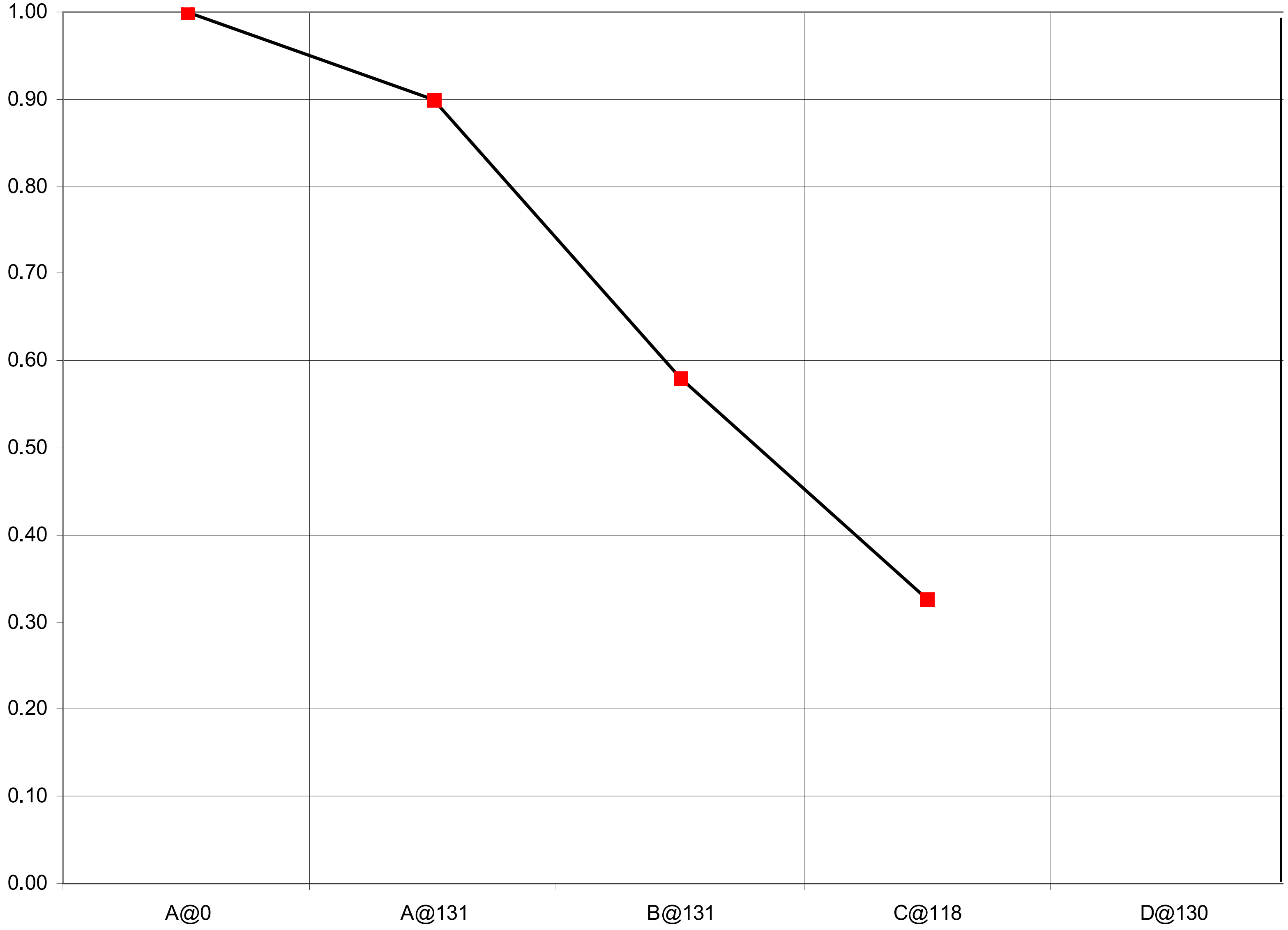
$$M = \frac{CR_2}{CR_1}$$

As + reactivity is added, Keff $_2$ approaches 1.
1/M approaches zero.

Example of 1/M Data

RCCA	CR	1/M
A@0	18	1.00
A@131	20	0.90
B@131	31	0.58
C@118	55	0.33

1/M Plot



1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
A@0
A@131
B@131
C@118
D@130

Reactivity Management Problems

TABLE 7.2-1 Incorrect ECRPs

Date	Plant	Primary Cause
5/11/85	V.C. Summer	Incorrect ECRP, went critical below the RIL, inverse multiplication plot failed to identify error.
5/17/85	McGuire 2	Incorrect ECRP, went critical below the RIL, error caused by incorrect Xenon worth program.
8/23/84	Turkey Point 3	Incorrect ECRP, went critical 85 steps below ECRP, calculation error.
5/12/84	Turkey Point 3	Incorrect ECRP, went critical 145 steps below ECRP, calculation error.
10/31/84	Turkey Point 4	Unable to achieve criticality, calculation error resulted in improper boron addition to RCS.
5/15/85	Turkey Point 3	Incorrect ECRP, used wrong RCS temperature in calculation (525°F vs. 535°F)

Recent Problems

- Fitzpatrick (BWR-4) 3/1997 @ 100%.
  - Performing rod coupling check.
  - RO looked at wrong position indication for selected rod.
  - Selected rod at mid-plane
  - Withdrew rod until auto rod block at 101%.

Recent Problems (continued - 1)

- Zion (4-loop W) 2/1997. Rx shutdown to Mode 3 in progress due to CS pump LCO expired.
  - RO continuously inserted rods (~ 4 minutes) until < POAH.
  - Rods below RIL.
  - Rx went subcritical.
  - Operator withdrew rods (~ 2 minutes) to restore power to POAH.

Recent Problems (continued - 2)

- Beaver Valley (3-loop W) 3/1996.
  - Shutdown in progress.
  - Concurrent rod drop testing in progress.
  - RO withdrew rods trying to maintain no-load Tave.
  - 0.95 SUR occurred.

Review Learning Objectives

- Briefly discuss the V.C. Summer startup accident.
- Explain the causes of the accident. Obj-2
- Explain the safety implications of the accident. Obj-3
- Explain what procedural limitations and administrative controls should have prevented this accident. Obj-4

Questions?

Equivalent Power for Xe Calculations

Hours Prior to Shutdown	Average Power (%)	Multiplier		Product
0 to 1		x6	=	
1 to 2		x5	=	
2 to 3		x5	=	
3 to 4		x5	=	
4 to 5		x4	=	
5 to 6		x4	=	
6 to 7		x4	=	
7 to 8		x4	=	
8 to 9		x4	=	
9 to 10		x3	=	
10 to 11		x3	=	
11 to 12		x3	=	
12 to 13		x3	=	
13 to 14		x3	=	
14 to 15		x3	=	
15 to 16		x3	=	
16 to 17		x2	=	
17 to 18		x2	=	
18 to 19		x2	=	
19 to 20		x2	=	
20 to 21		x2	=	
21 to 22		x2	=	
22 to 23		x2	=	
23 to 24		x2	=	
24 to 25		x2	=	
25 to 26		x1	=	
26 to 27		x1	=	
27 to 28		x1	=	
28 to 29		x1	=	
29 to 30		x1	=	
30 to 31		x1	=	
31 to 32		x1	=	
32 to 33		x1	=	
33 to 34		x1	=	
34 to 35		x1	=	
35 to 36		x1	=	
		TOTAL	=	

$$\text{Xenon Power} = \frac{\text{TOTAL}}{91} = \frac{\_\_\_\_}{91} = \_\_\_\_\_\%$$

Equivalent Power for Sm Calculations

Days Prior to Shutdown	Average Power (%)	Multiplier		Product
Today	______	x15.6	=	______
1	______	x24.7	=	______
2	______	x18.1	=	______
3	______	x13.2	=	______
4	______	x 9.6	=	______
5	______	x 7.0	=	______
6	______	x 5.2	=	______
7	______	x 3.8	=	______
8	______	x 2.8	=	______
		TOTAL	=	______

Samarium Power = $\frac{\text{TOTAL}}{100} = \frac{\_\_\_\_\_\_}{100}$ = ______ %

Indications that the Rx is Critical

- Increasing neutron population.
- Constant, positive startup rate.
- No reactivity addition:
  - no rod motion.
  - no change in boron concentration.