EVENT TREE ANALYSIS

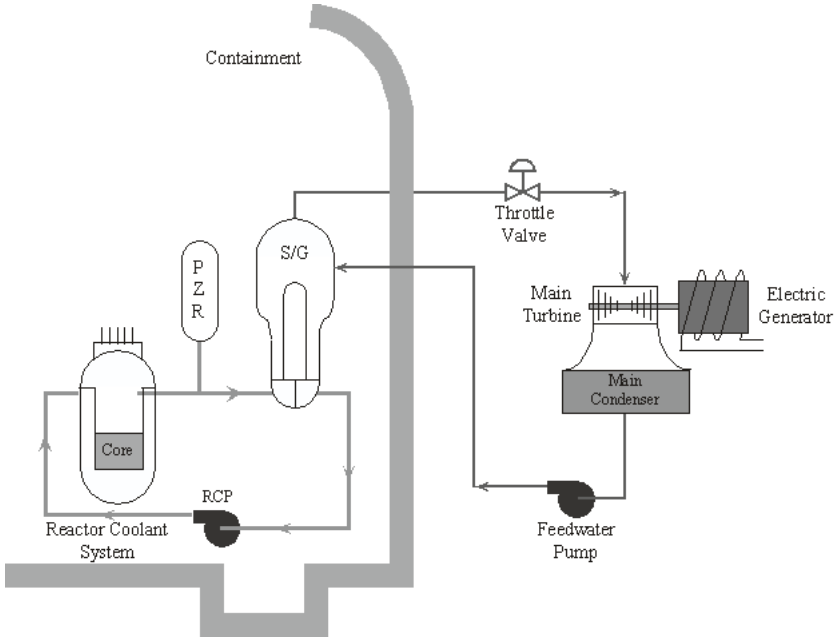
Nuclear Safety Overview

- How does a nuclear reactor work?
- What can go wrong?

Types of Nuclear Power Plants

- Nuclear power plants generate electricity
- Two types of nuclear power plants are in commercial operation in the U.S.:
  - Pressurized water reactors (PWR)
  - Boiling water reactors (BWR)

Pressurized Water Reactors

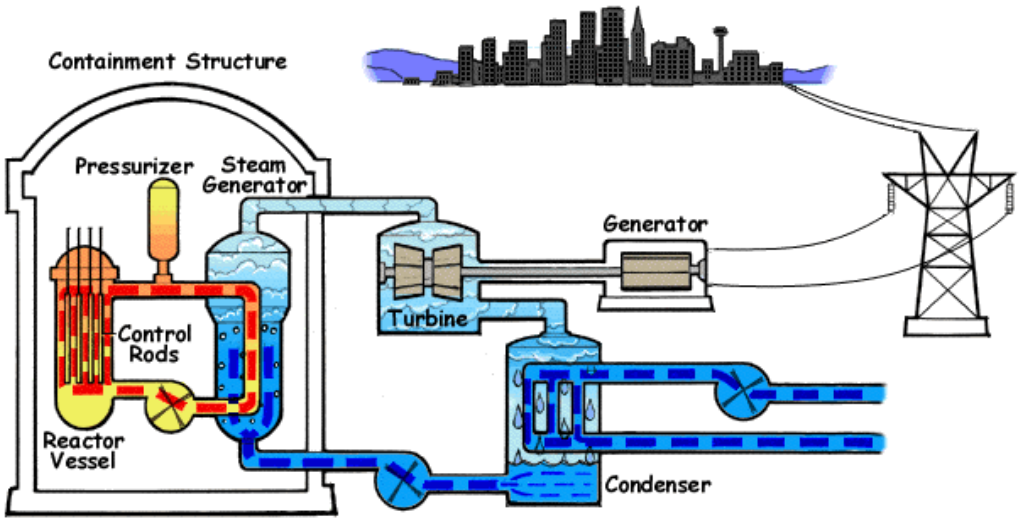


- The reactor core creates heat
- Pressurized water in the reactor-coolant system carries the heat to the steam generator
- The steam generator vaporizes the water in the secondary loop to drive the turbine, producing electricity

Links and Notes:

http://www.nrc.gov/reactors/pwrs.html

Pressurized Water Reactors



A PWR keeps the primary system under pressure
The reactor coolant heats up, but does not boil
The reactor coolant (primary system, red) and the water that boils (secondary system, blue) never mix
That keeps most of the radioactivity in the reactor area

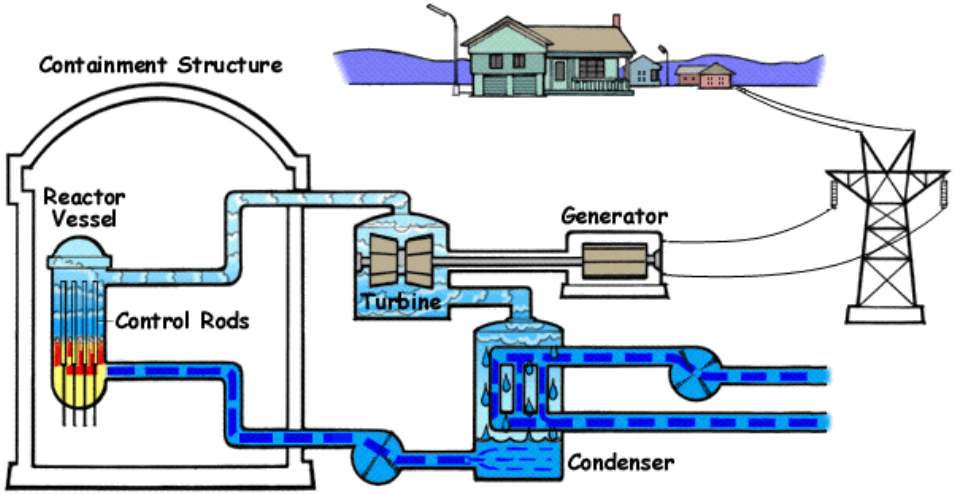
Accident Prevention (PWR)

- Reactor-coolant pumps circulate water in primary system
- High- and low-pressure injection pumps:
  - Inject water into the primary system
  - In case of a leak or pipe break
- Also recirculation of water from the sump
- Main and auxiliary feed water pumps:
  - Remove heat from the steam generators
  - (Secondary system)
- Service water system:
  - Ultimate heat sink (may not be clean water)
- Component-cooling water system:
  - Provides cooling to major rotating equipment (pumps)

Accident Mitigation

- Fission-product removal:
  - Scrub radioactivity from air inside containment
  - E.g., containment sprays
- Containment integrity:
  - Heat removal
  - Pressure suppression or relief

Boiling Water Reactors



- The reactor core creates heat
- A single loop both delivers steam to the turbine, and returns water to the reactor core to cool it
- Theoretically simpler, but more components get radioactive

Links and Notes:

http://www.nrc.gov/reactors/bwrs.html

What can go wrong?

- Loss of reactor coolant (leak, pipe break)
- Loss of electric power to key components
- Loss of ultimate heat sink (service water)
- Transients in power level, etc.

Event-Sequence Quantification

$$\phi(S) = \phi(I) f(A \mid I) f(\bar{B} \mid IA) f(C \mid IA\bar{B}) f(\bar{D} \mid IA\bar{B}C)$$

WHERE

$\phi(S)$ = the frequency of scenario S

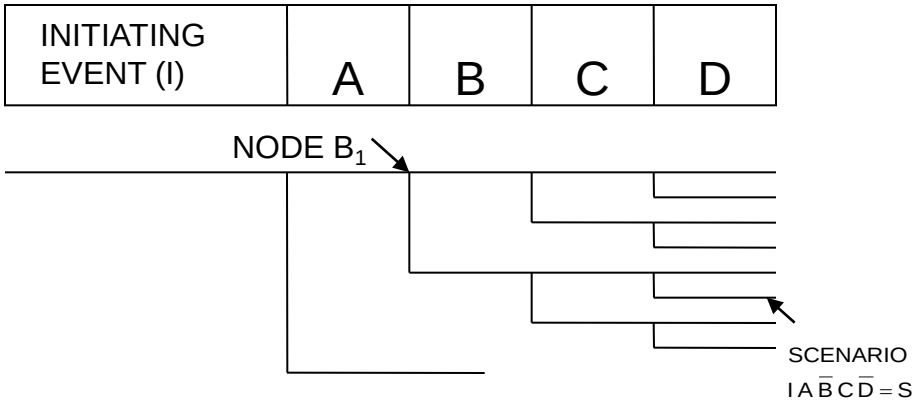
$\phi(I)$ = the frequency of initiating event I

$f(A \mid I)$ = the fraction of times system A succeeds given that I has happened

$f(\bar{B} \mid IA)$ = the fraction of times system B fails given that I has happened and A has succeeded

$f(C \mid IA\bar{B})$ = the fraction of times C succeeds given that I has happened, A has succeeded, and B has failed

$f(\bar{D} \mid IA\bar{B}C)$ = the fraction of times D fails given that I happened, A succeeded, B failed, and C succeeded



SIMPLE EVENT TREE

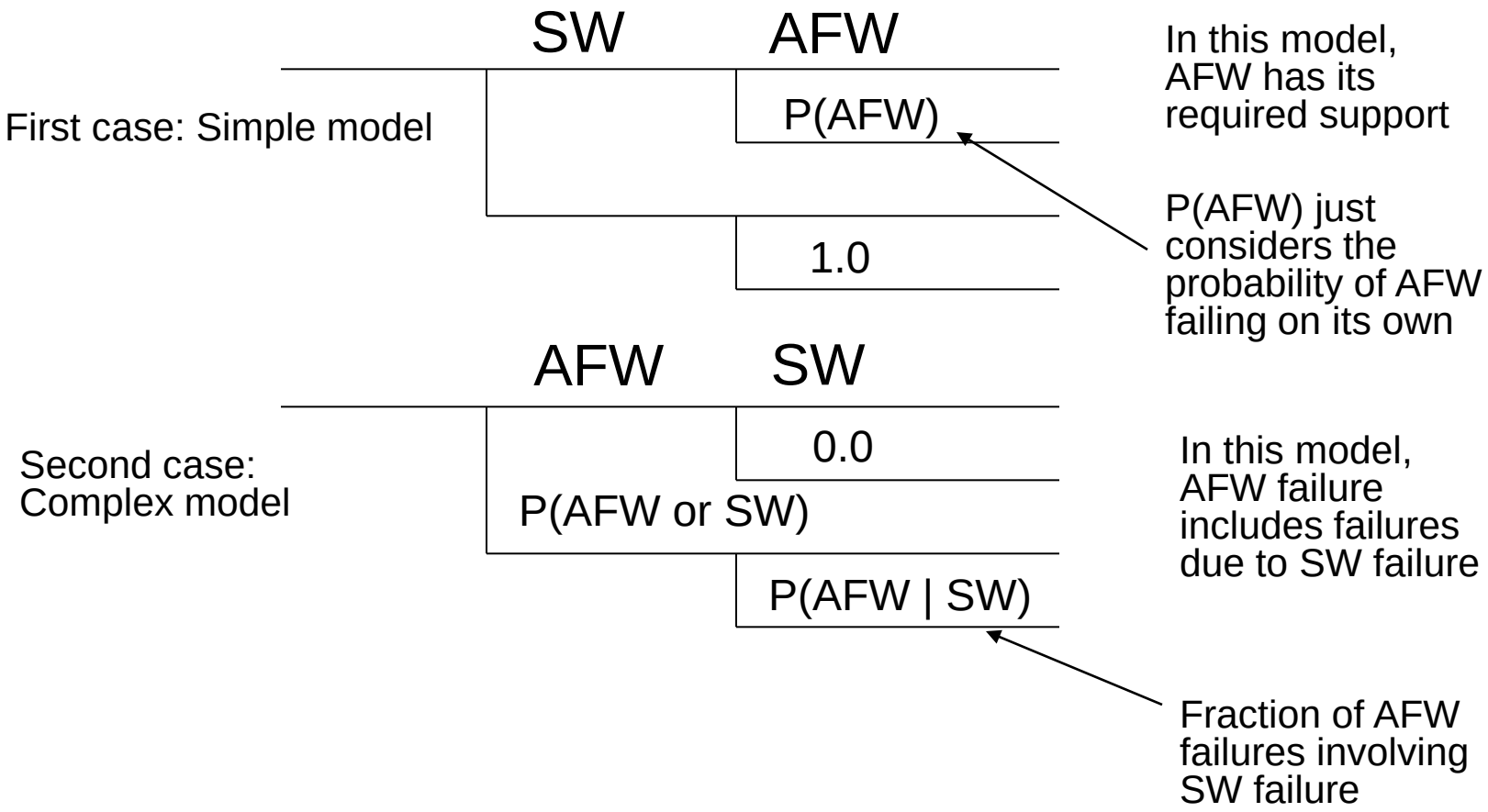
Probabilities of system success and failure are sometimes called “split fractions”

Event Tree Analysis

- Simpler than fault-tree analysis:
  - Sequence frequencies are products
  - Can combine sequences by taking sums
- However, more judgment is required in how to model a system as an event tree
- Basic goal is to keep the model as simple as possible:
  - By taking advantage of independence and conditional independence relations

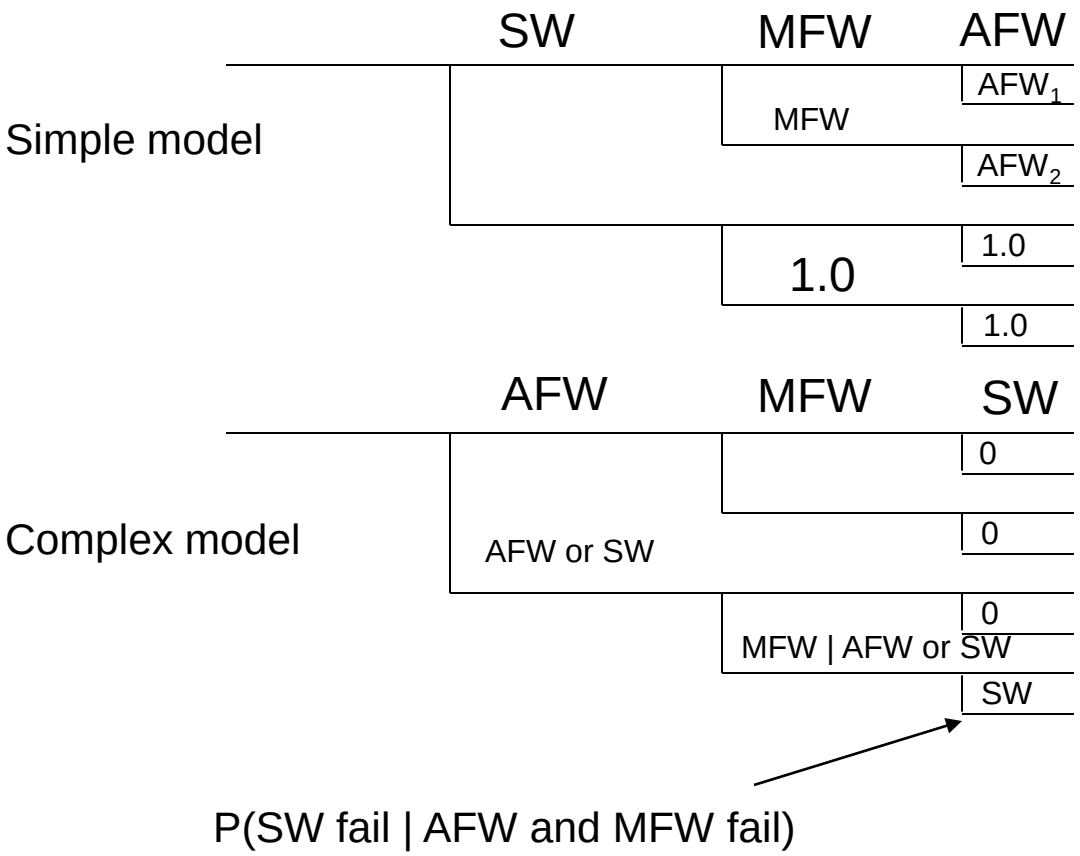
Event Tree Analysis

- Consider service water and auxiliary feed water:
  - Auxiliary feed water (AFW) requires service water (SW)



Use of Conditional Independence

- Both main feed water (MFW) and auxiliary feed water (AFW) require service water (SW) to operate



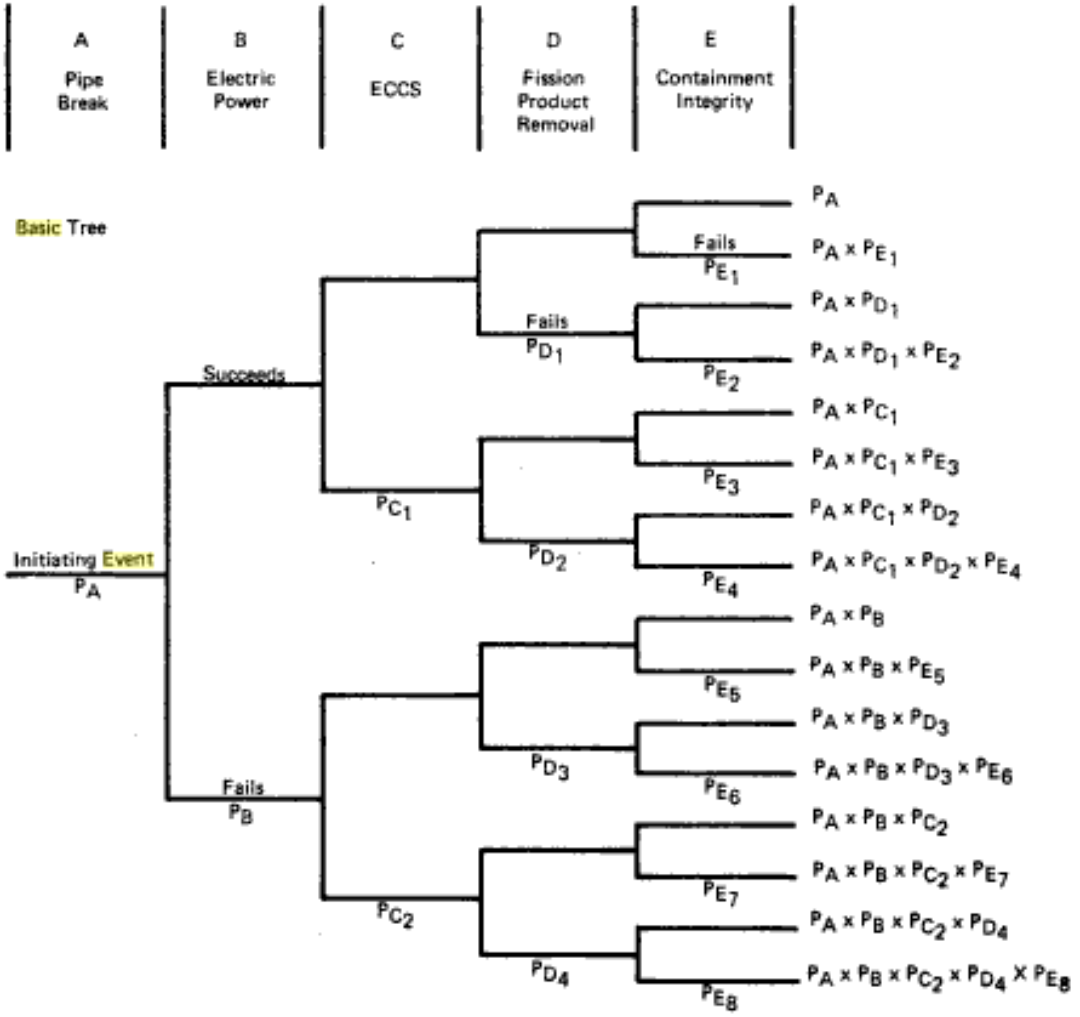
MFW and AFW may be conditionally independent given success of SW

In other words, we may have $AFW_1=AFW_2$

SW and MFW are not conditionally independent given failure of AFW

P(SW fail) takes into account the possibility that AFW and MFW fail due to SW failure

More Realistic Event Tree



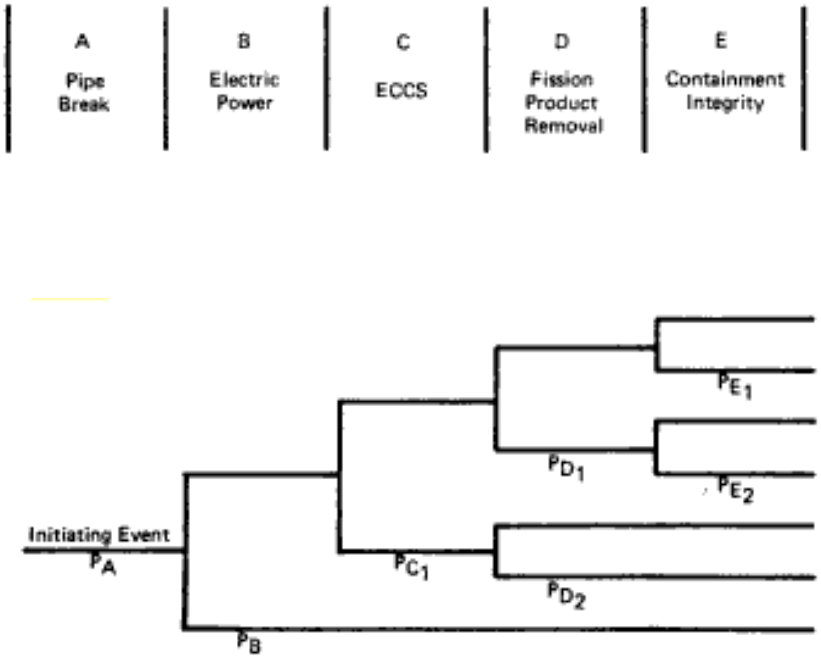
Source: McCormick, Ch. 9, pp.193-196

Simplifications

If electric power fails, other systems also fail:
- Emergency core cooling system (ECCS)
- Fission product removal
- Containment integrity

If ECCS fails:
- Then containment integrity also fails

Simplified Realistic Event Tree



For more information on reduced event trees, see McCormick, Ch. 9, pp. 200-201

Event Tree Analysis

For more examples, see:

McCormick, Chapter 9

Reactor Safety Study, Appendix I (WASH-1400)

Accident Sequence Precursor Study (discussed in http://www.riskinstitute.org/NR/rdonlyres/C1DC8DB5-66E3-46AD-8CFA-ED3CC9CF1B35/0/NAE_89100.pdf)