Chemical Engineering 512

Nuclear Reactor Transient Modeling

Lecture 1

Introduction

Hard Work + The Spirit

Face the future with optimism. I believe we are standing on the threshold of a new era of growth, prosperity, and abundance. Barring a calamity or unexpected international crisis, I think the next few years will bring a resurgence in the economy as new discoveries are made in communication, ***medicine***, ***energy***, ***transportation***, physics, ***computer technology***, and ***other fields*** of endeavor.

Many of these discoveries, as in the past, will be ***the result of the Spirit whispering insights into and enlightening the minds of truth-seeking individuals***. Many of these discoveries will be made for the purpose of helping to bring to pass the purposes and work of God and the quickening of the building of His kingdom on earth today. With these discoveries and advances will come new employment opportunities and prosperity *for those who work hard and especially to those who strive to keep the commandments of God*. This has been the case in other significant periods of national and international economic growth.

-Elder M. Russell Ballard

BYU Idaho Commencement Remarks

April 6, 2012

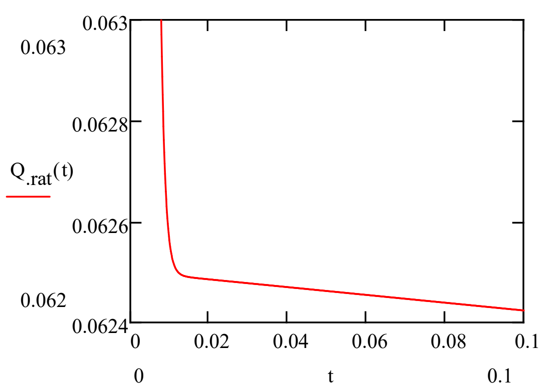
Family

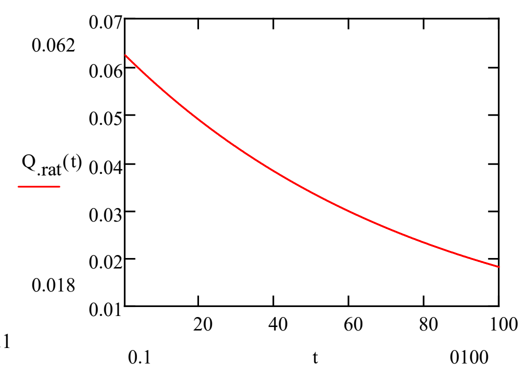
Course Guidance

- TA: Jackson Ivory
- Weekly Homework (30%)
- Attendance/Participation (30%)
- Final Project (40%)
  - Last 2 days of class will be final presentations
  - Do NOT procrastinate!!!!
- Plagiarism/Ethics
- Export Control

Shutdown Fission Heat

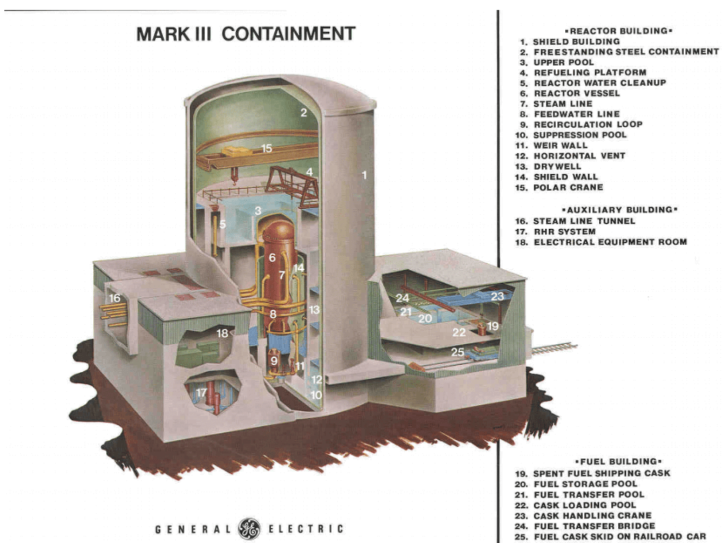
- Even after shutdown heat is produced
  - Fissions
    - Solve kinetic eqns. → large negative reactivity
    - $\phi(t) = \phi_o \left[\frac{\beta}{\beta-\rho} e^{-\gamma_1 t} - \frac{\rho}{\beta-\rho} e^{-\frac{(\beta-\rho)t}{l}} \right]$
      - ➢ Could lead to system boundary failure
      - ➢ Leads to release of radioactive material
      - ➢ Leads to dose to the public
      - ➢ Leads to deaths/injuries – hugely publicized!!!

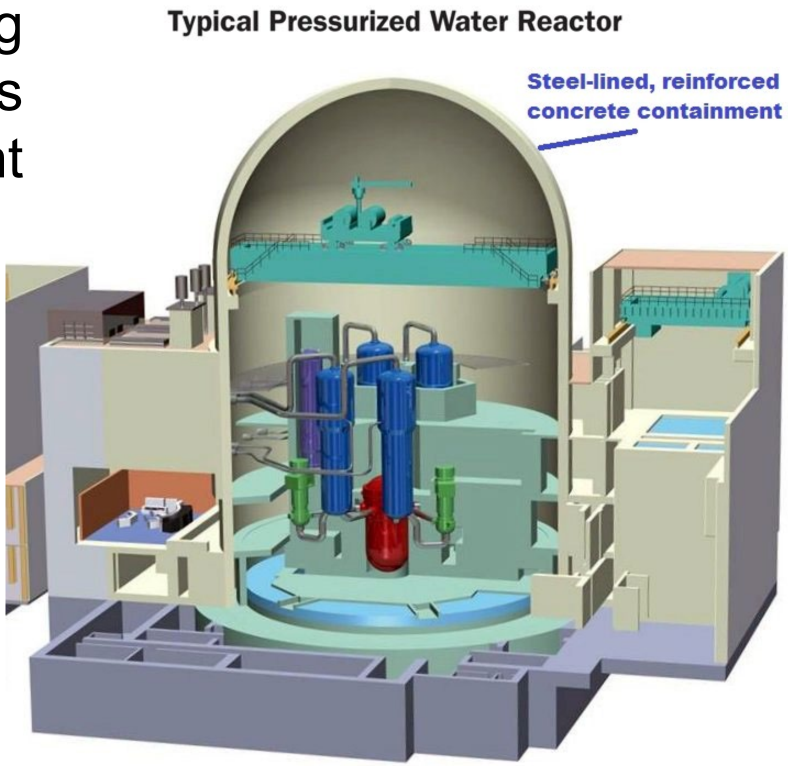




How to ensure safety?

- Engineering
- Procedures
- Safety Systems/Equipment





Source: U.S. Nuclear Regulatory Commission

The Nuclear Dilema!

- Show me that a car never built before will be safe no matter what, in all conditions, accidents and scenarios.
  – You can't drive the car
  – You can't build the car
  – Past data will not be accepted except under specific and limited circumstances?
- USNRC takes similar position:
  – "Show us that your reactor is exceptionally safe, under all conditions, but you can't build or even fuel the reactor."

Purpose of Nuclear Safety Analysis

To satisfy licensing requirements by:

- Preventing dose to public
  - If dose occurs, minimize it
  - Evaluate max dose possible for DBA
- Minimize total dose to personnel/environment
- Minimize damage to core
  - Core Damage Frequency (CDF)
- Protect Investment
  - Don’t want to wreck the plant (lots of lost $$$)

Design Basis Accidents (DBA)

- **Design-basis criticality**: A criticality accident that is the most severe design basis accident of that type applicable to the area under consideration.
- **design-basis earthquake** (DBE): That earthquake for which the safety systems are designed to remain functional both during and after the event, thus assuring the ability to shut down and maintain a safe configuration.
- **Design-basis event** (DBE): A postulated event used in the design to establish the acceptable performance requirements of the structures, systems, and components.
- **Design-basis explosion**: An explosion that is the most severe design basis accident of that type applicable to the area under consideration.
- **Design-basis fire:** A fire that is the most severe design basis accident of this type. In postulating such a fire, failure of automatic and manual fire suppression provisions shall be assumed except for those safety class items or systems that are specifically designed to remain available (structurally or functionally) through the event.
- **Design-basis flood**: A flood that is the most severe design basis accident of that type applicable to the area under consideration.
- **Design-basis tornado (DBT):** A tornado that is the most severe design basis accident of that type applicable to the area under consideration.
- Most Common:
  - LOCA, LOFA, Overpower

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Beyond Design Basis Accidents (BDBA)

- Beyond scope of design
  - Unlikely events
  - Extreme conditions
- Extremely severe
- Station Blackout
  - Fukushima
  - Significant focus
- Have additional equipment/procedures (not safety grade) to help with these.

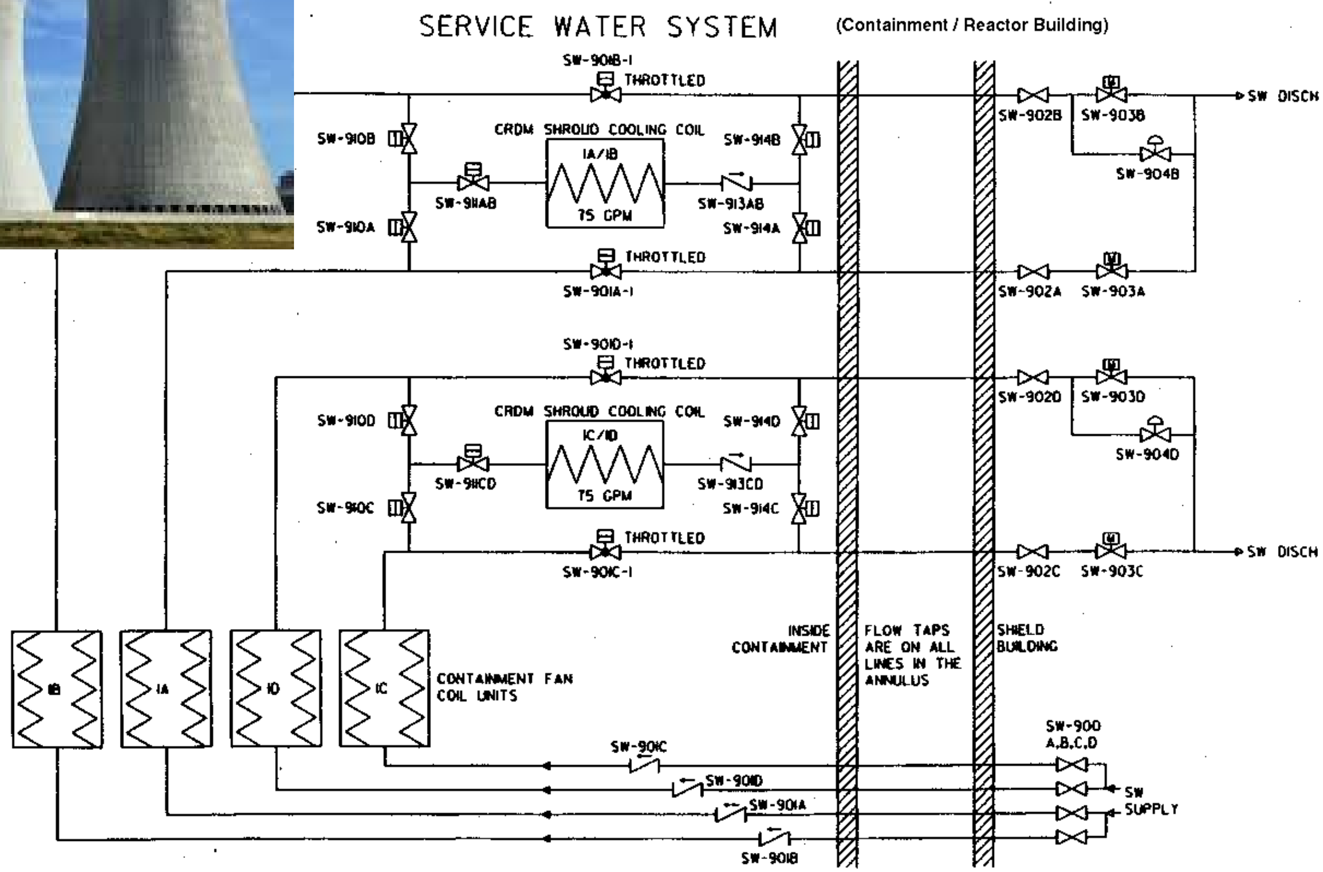
Ensuring Safety?

- Design
  - Undermoderated vs. Overmoderated
  - Negative reactivity feedback coefficients
  - CDF < 1E-6 for all Design Basis Accidents (DBA)
- Operation
  - Tech Specs – how reactor is run
    - "Control Rod movement < 20 steps per hour…"
- Margins
  - Limiting conditions of plant – SS and Transient

The Reactor Protection System (RPS)

- Control rods
- Safety Injection/Standby liquid control

Essential Service Water System (ESWS)



Emergency Core Cooling System (ECCS)

- High Pressure Safety Injection System (HPSI)
  - Initiated by:
    - Low pressurizer pressure
    - High containment pressure
    - Steam line pressure/flow anomalies
- Automatic Depressurization System
  - 7 SRVs in vessel head
  - Rapidly decrease system pressure
  - Initiated by low level + time delay

ECCS (continued)

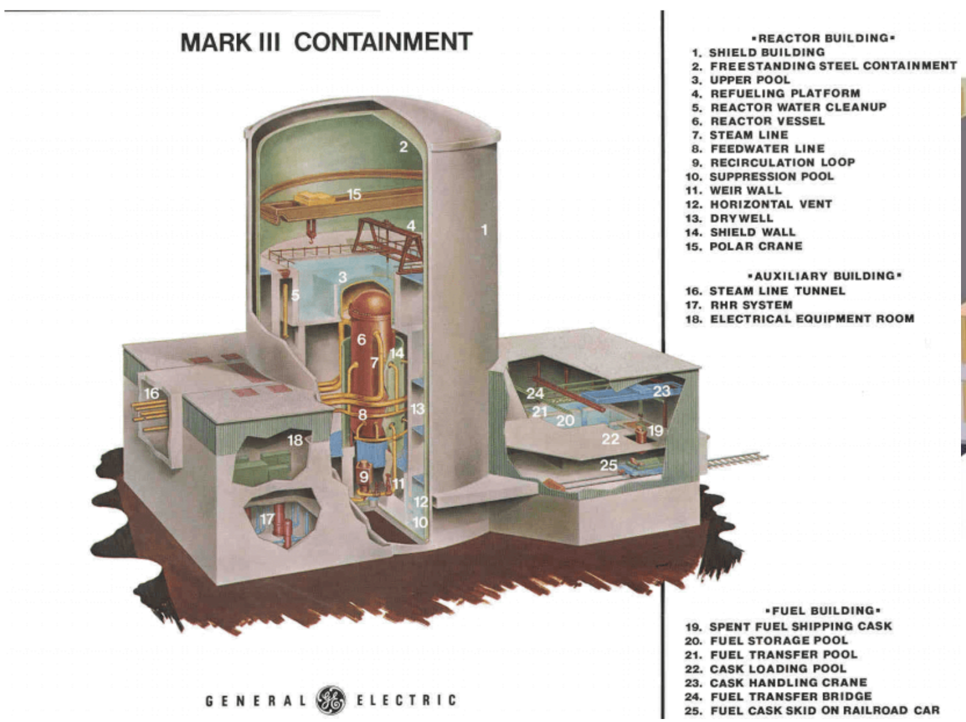
- Low Pressure Safety System (HPSI)
  - Only functions after blowdown
    - Larger supply
    - Later in accident
- Containment cooling system
  - Spray system
    - Actuated by high containment pressure/temperuture
- Core Spray System
  - (BWR only)

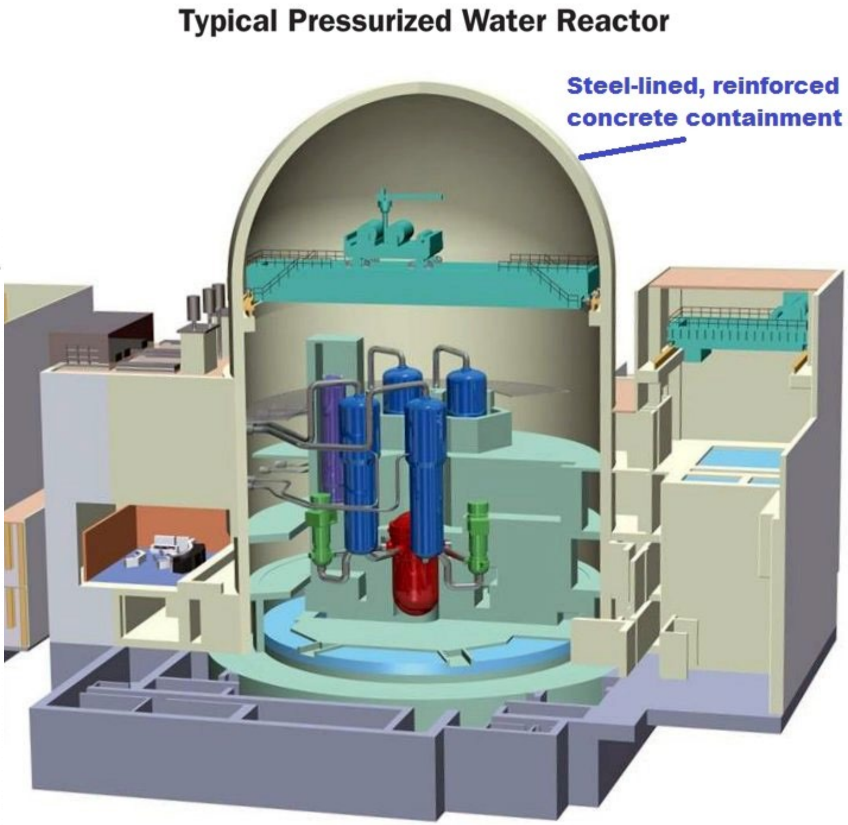
Emergency Electrical Systems (EES)

- Diesel Generators
- Flywheels
- Batteries

Containment Systems

- Clad
- Containment
- Secondary Containment

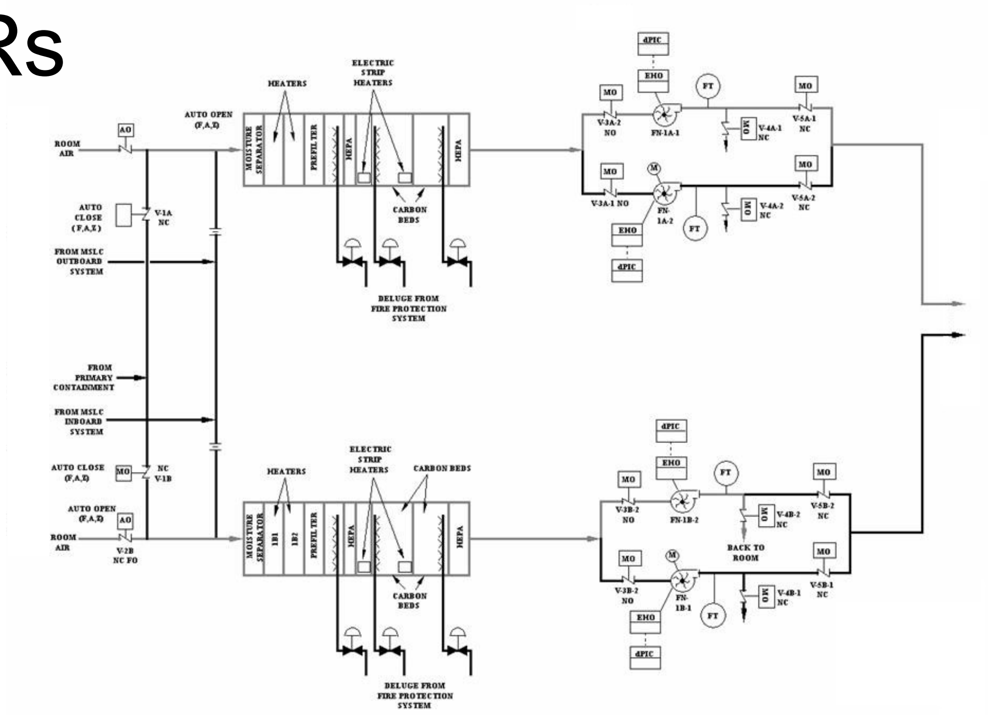




Source: U.S. Nuclear Regulatory Commission

Standby Gas Treatment Systems (SBGT)

- Secondary Containment
  - Maintain negative pressures
  - (pull air in, rather than release radioactivity)
- Primarily for BWRs



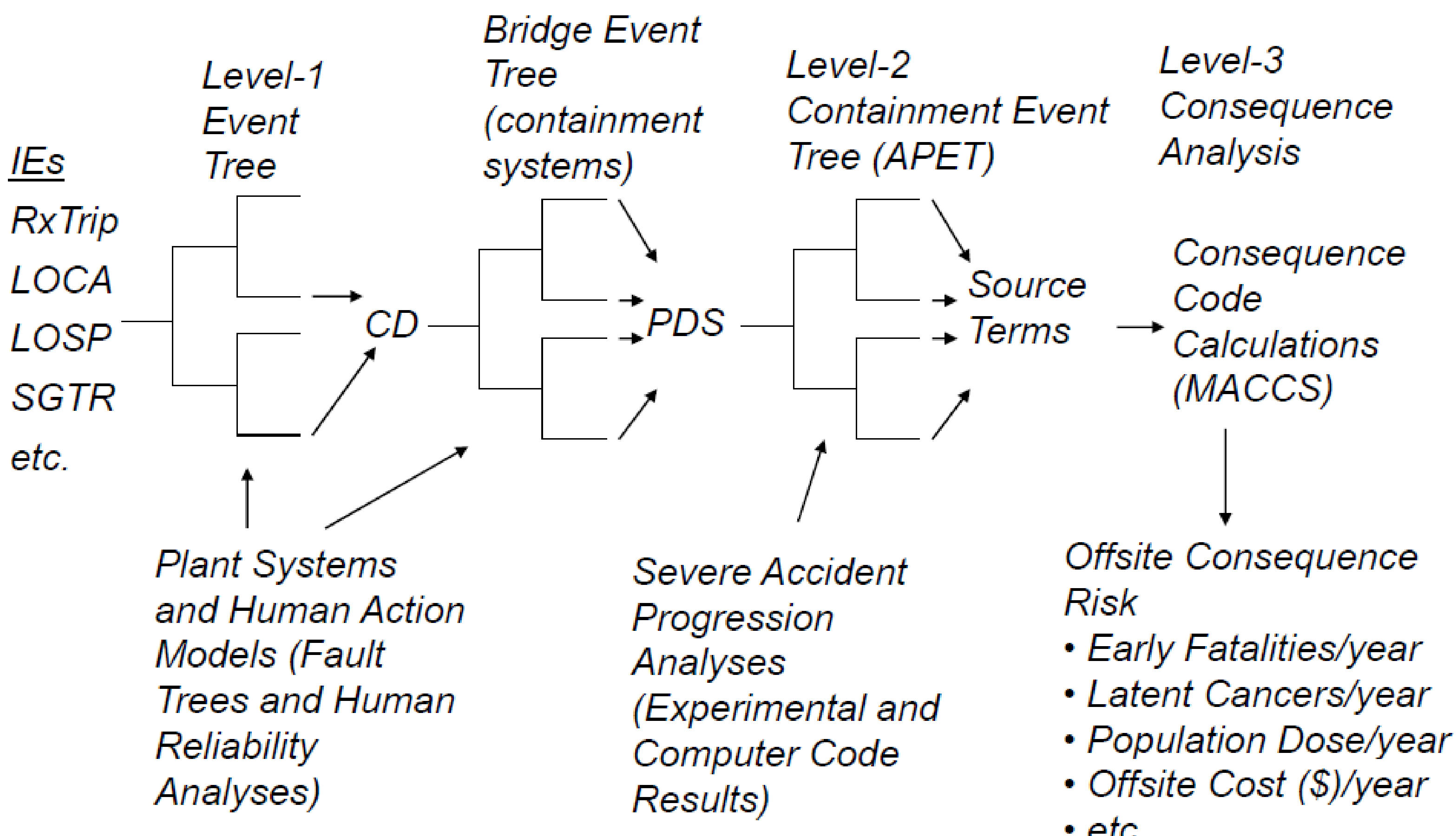
Ventilation and Radiation Protection Systems

- Prevention of radiation gas release
  - Auxiliary Building
  - Shield Building
  - Reactor Building
  - Turbine Building
  - Radwaste Building
  - Control Room
  - Screenhouse
- Vent, Filter, Blowers

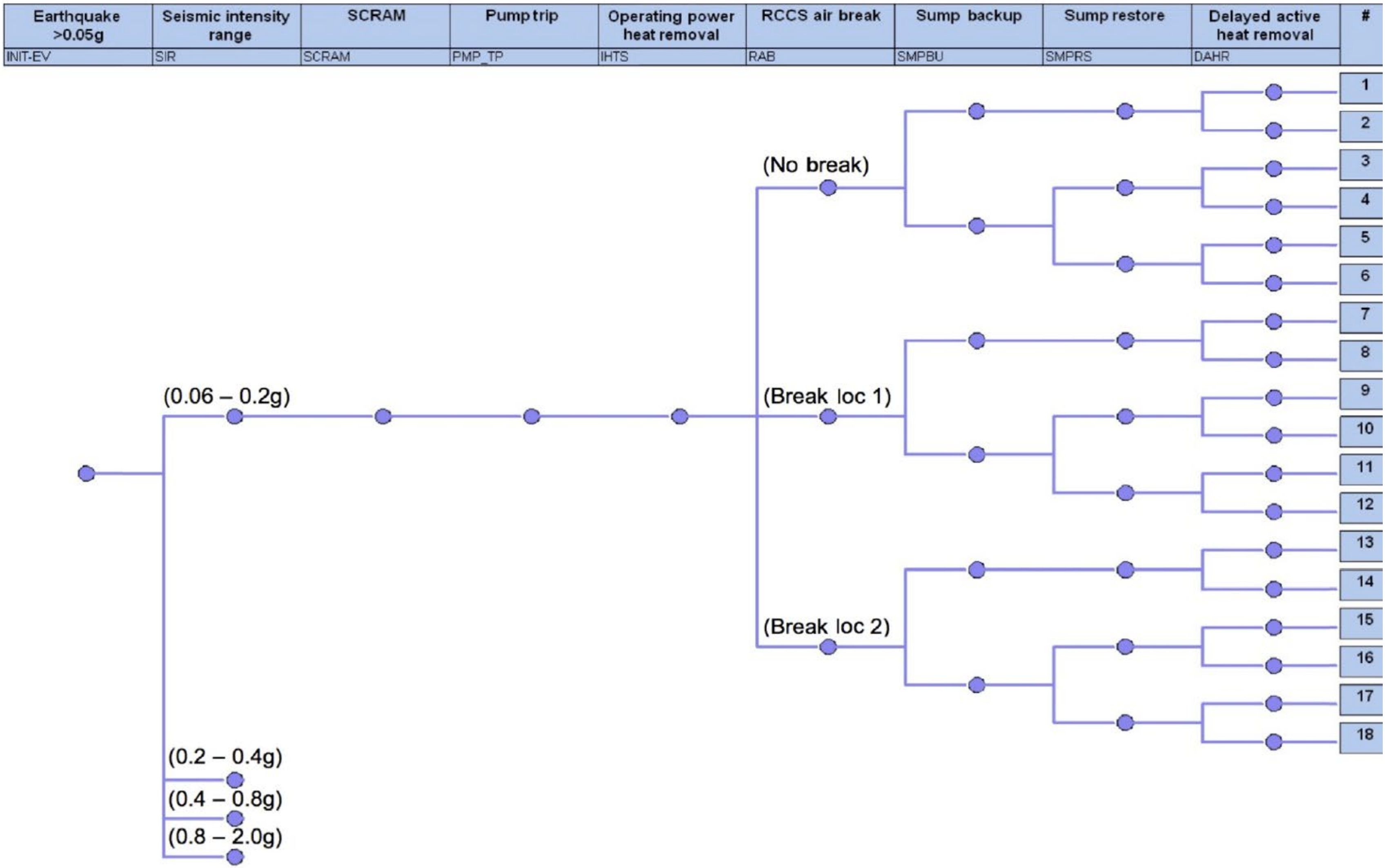
Probability Risk Assessment

$$\text{Risk}\left[\frac{\text{Consequence Magnitude}}{\text{Unit of Time}}\right] =$$

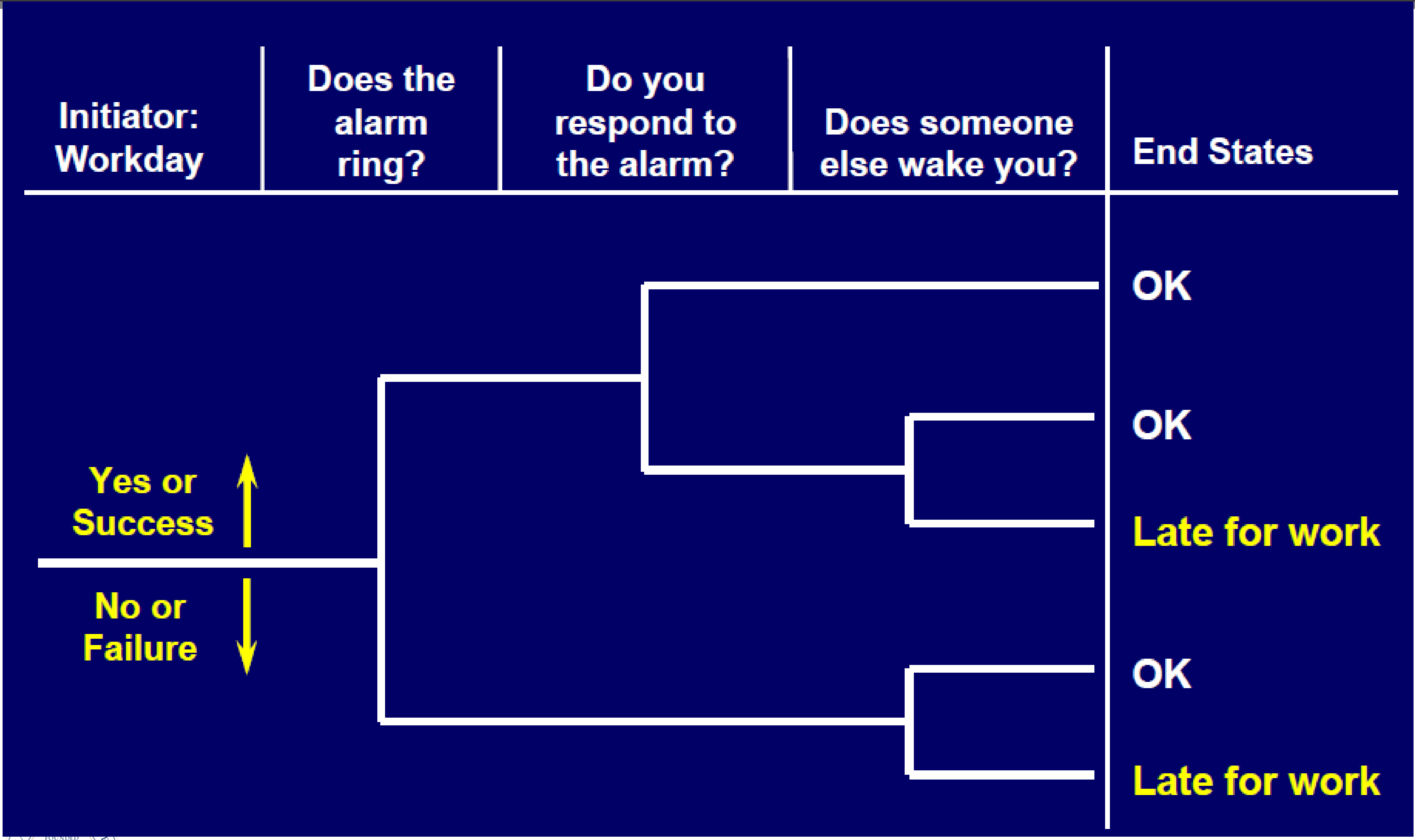
$$\text{Frequency}\left[\frac{\text{Events}}{\text{Unit of Time}}\right] \times \text{Consequences}\left[\frac{\text{Magnitude}}{\text{Event}}\right]$$



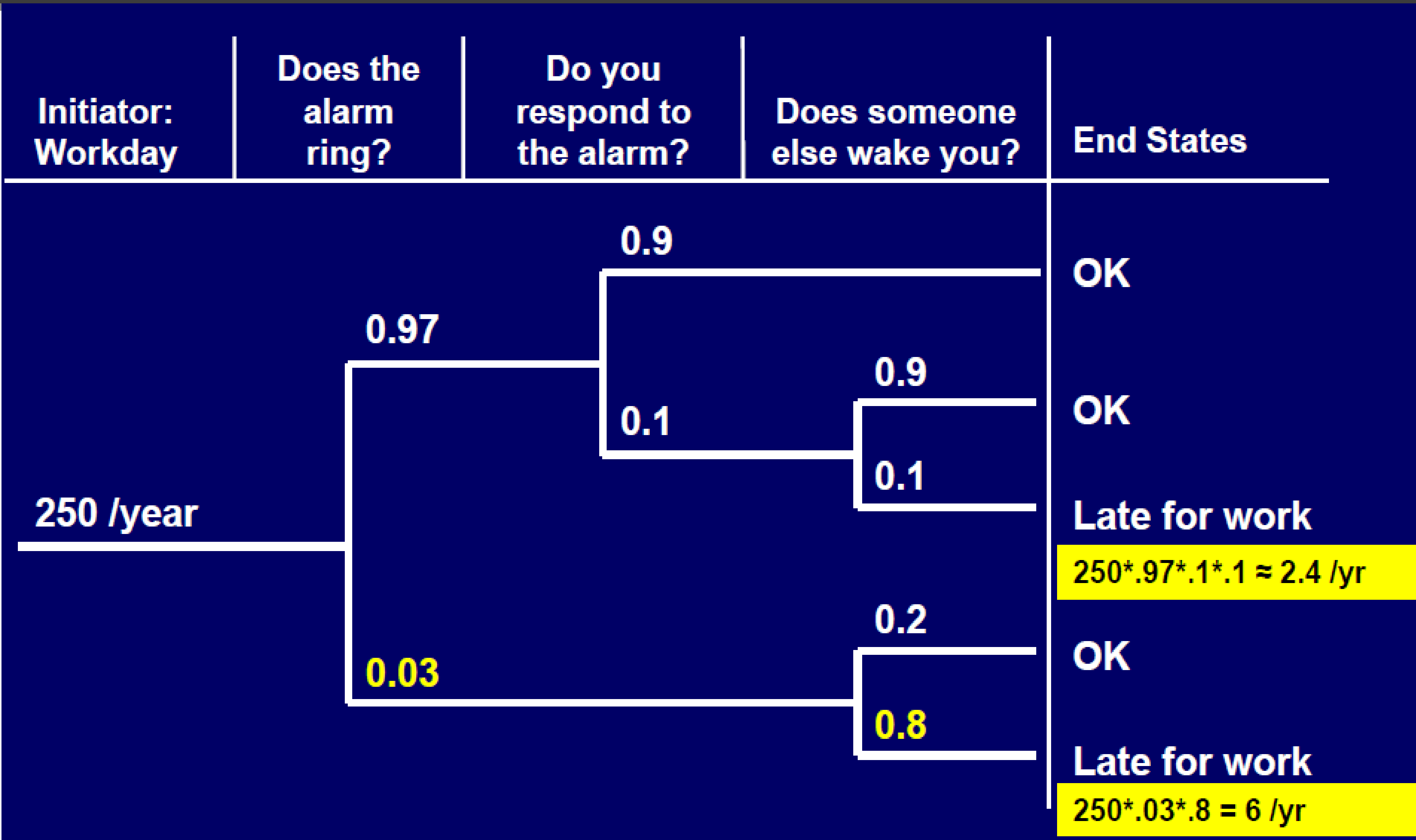
Fault Tree Analysis



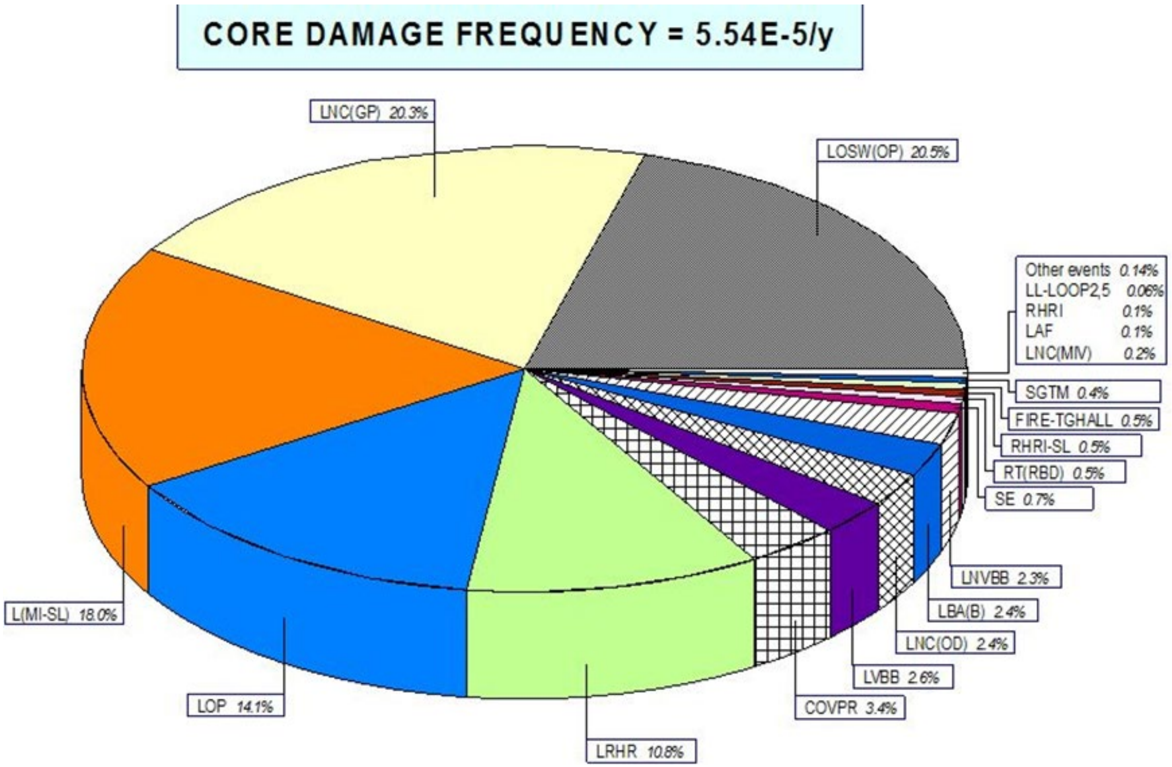
Probabilistic Example



Probabilistic Example



Final Result – Dose vs. Frequency



How do we get RISK numbers?

- Vendors provide the numbers
- Experiments
  - Start with separate effects experiments
  - Move to integral effects experiments
  - Pilot plant experiments
  - Intertrial Demonstrations
- MODELING and SIMULATION!!!
  - Must be NRC approved software ($100M+)
  - Must have rigorous quality control on inputs
  - Ultimately need uncertainty quantificaiton

RELAP5-3D

- Reactor Excursion and Leak Analysis Program
- NRC Approved
- System Modeling software → ASPEN/HYSIS
- Developed in 1980's
- Ubiquitous use!

RELAP5-3D Training Discs

- Will be used in lieu of textbook
- Watching is essential! Will not repeat content in class!!
- DVD Training videos available on Learning Suite and via flash drive
- 10 DVDs
  - Each split into sections
- You will be required to watch sections before each class
- Print Appendix A (input manual)

Assignment

- Before Thursday’s class, watch sections 1-4 on DVDs
- Install text editor of choice (Notepad ++)
- Homework 1 is due next Tuesday (9/1)