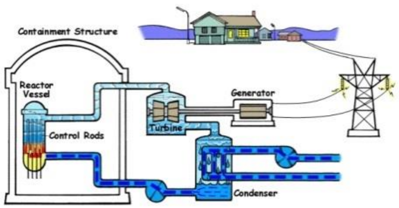
Thermal Power Stations II



Faculty of Engineering
Mechanical Engineering Dept.

Lecture (7)
on
Safety System of Nuclear Power Stations

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Ethical Problems in Nuclear Power Regulation

Promoting Nuclear Power

- funded research in plant design
- subsidized production of nuclear fuel

Regulating Plant Safety

- defined safety procedures, poor enforcement
- inspecting, certifying plants
- certifying operators, poor training

As a result of these conflicting interests

No Long Term Waste Disposal Plan was Completed

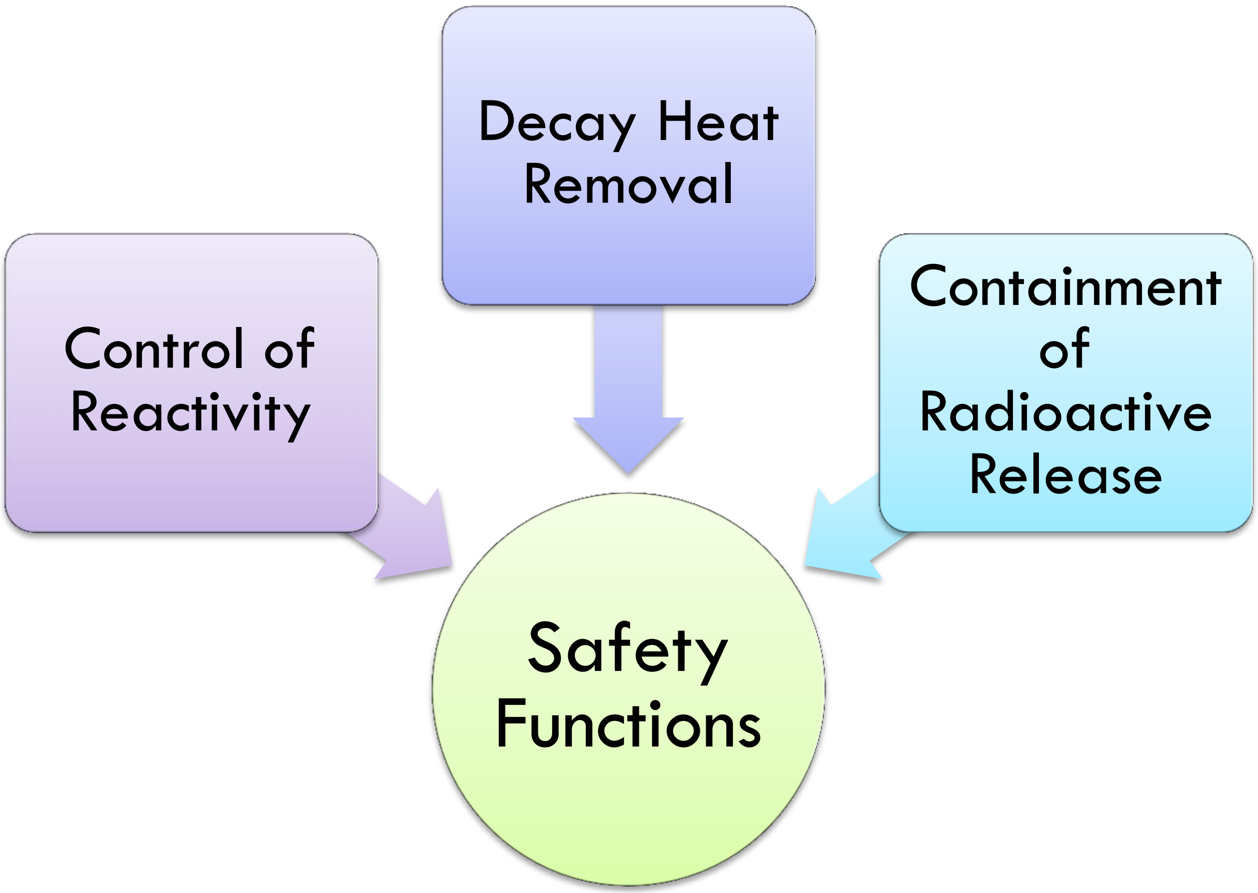
- wastes are still accumulating in temporary storage
- radioactive waste?

Future Termination/Cleanup Costs are not Factored into Current Electric Rates

Power Companies are Largely Self-Regulated

- avoid reporting radiation release or do not monitor releases.
- avoid safety regulations to save money.

Design Basis of Safety System



Safety Systems

Active Safety Systems

- Pressurizing System
- Emergency Boron Injection System
- Emergency Feed Water System
- Residual Heat Removal System
- Double Containment
- Spray System
- Emergency Power Supply System

Passive Safety Systems

- Emergency Core Cooling System (Passive Part)
- Passive Containment Heat Removal System
- Passive SG Heat Removal System
- Passive Hydrogen Removal System
- Passive Reactor Scram System
- Passive Corium Catcher

Reactor Protection system

A reactor protection system is designed to immediately terminate the nuclear reaction. By breaking the chain reaction, the source of heat is eliminated. Other systems can then be used to remove decay heat from the core. All nuclear plants have some form of reactor protection system.

Control rods

Control rods are a series of rods that can be quickly inserted into the reactor core to absorb neutrons and rapidly terminate the nuclear reaction. They are typically composed of actinides, lanthanides, transition metals, and boron, in various alloys with structural backing such as steel. In addition to being neutron absorbent, the alloys used also have to have at least a low coefficient of thermal expansion so that they do not jam under high temperatures, and they have to be self-lubricating metal on metal, because at the temperatures experienced by nuclear reactor cores oil lubrication would foul too quickly.

Reactor Protection system

Standby liquid control

Boiling water reactors are able to scram the reactor completely with the help of their control rods. The standby liquid control system consists of a solution containing boric acid, which acts as a neutron poison and rapidly floods the core in case of problems with the stopping of the chain reaction.

Pressurized water reactors on the other hand have to use boron solution in addition to the control rods to shut down the reactor. In the case of problems with the control rods, they are able to increase the normal concentration of boron in the coolant water rapidly, with the help of emergency boric acid tanks.

Controlling on Reactor According Operation Condition

Normal condition

When the reactor is normally operating, the chain reaction (or power level) is controlled by moving adjuster rods and varying the water level in vertical cylinders. Sensitive detectors constantly monitor different aspects, like temperature, pressure and the reactor power level. When necessary, reactors can safely and automatically shut down within seconds.

Controlling on Reactor According Operation Condition

Shutdown condition

- Almost nuclear reactors have two independent, fast-acting and equally effective shutdown systems.
- The first shutdown system is made up of rods that drop automatically and stop the chain reaction if something irregular is detected.
- The second shutdown system injects a liquid, or poison, inside the reactor to immediately stop the chain reaction.
- Both systems work without power or operator intervention. However, they can also be manually activated.

Controlling on Reactor According Operation Condition

Restarting condition

Once a reactor is shut down, it will stay that way until restarted by the operators in the control room.

There is no possibility of the reactor accidentally restarting on its own after it's shut down. The reactor must be manually restarted. This is another important safety feature.

Emergency Core Cooling System

Emergency core cooling systems (ECCS) are designed to safely shut down a nuclear reactor during accident conditions.

The ECCS allows the plant to respond to a variety of accident conditions and additionally introduce redundancy so that the plant can be shut down even with one or more subsystem failures.

In most plants, ECCS is composed of the following systems:

1. High pressure coolant injection system

HPCI consists of a pump or pumps that have sufficient pressure to inject coolant into the reactor vessel while it is pressurized. It is designed to monitor the level of coolant in the reactor vessel and automatically inject coolant when the level drops below a threshold. This system is normally the first line of defense for a reactor since it can be used while the reactor vessel is still highly pressurized.

Emergency Core Cooling System

2. Automatic Depressurization system

ADS consists in the case of Boiling water reactors of a series of valves which open to vent steam several feet under the surface of a large pool of liquid water in pressure suppression type containments, or directly into the primary containment structure in other types of containments, such as large-dry or ice-condenser containments. The actuation of these valves depressurizes the reactor vessel and allows lower pressure coolant injection systems to function, which have very large capacities in comparison to high pressure systems. Some depressurization systems are automatic in function but can be inhibited, some are manual and operators may activate if necessary.

Emergency Core Cooling System

3. Low pressure coolant injection system

LPCI consists of a pump or pumps that inject coolant into the reactor vessel once it has been depressurized. In some nuclear power plants, LPCI is a mode of operation of a residual heat removal system (RHS).

4. Core spray system (only in BWRs)

This system uses special spray nozzles within the reactor pressure vessel to spray water directly onto the fuel rods, suppressing the generation of steam. Reactor designs can include core spray in high-pressure and low-pressure modes.

Emergency Core Cooling System

5. Containment spray system

This system consists of a series of pumps and special spray nozzles that spray coolant into the primary containment structure. It is designed to condense the steam into liquid within the primary containment structure to prevent overpressure, which could lead to leakage, followed by involuntary depressurization.

6. Isolation cooling system

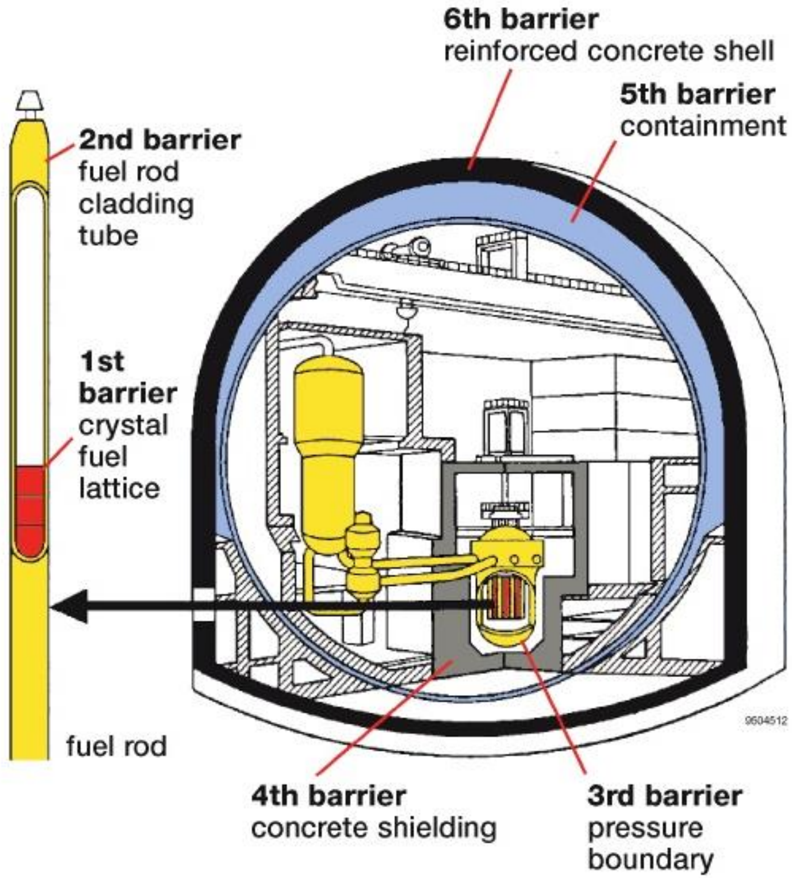
This system is often driven by a steam turbine to provide enough water to safely cool the reactor if the reactor building is isolated from the control and turbine buildings. Steam turbine driven cooling pumps with pneumatic controls can run at mechanically controlled adjustable speeds, without battery power, emergency generator, or off-site electrical power. The Isolation cooling system is a defensive system against a condition known as station blackout. It should be noted this system in not part of the ECCS and does not have a low coolant accident function. For Pressurized water reactors, this system acts in the secondary cooling circuit and is called Turbine driven auxiliary feed water system.

Design Considerations on Safety System

Multiple Barriers

There are barriers for various purposes:

- Containment of radioactive materials
- Radiation protection
- Fire protection
- Limitation of effects of component failures
  - Missiles
  - Flooding
- Physical protection (security)
- …



Design Considerations on Safety System

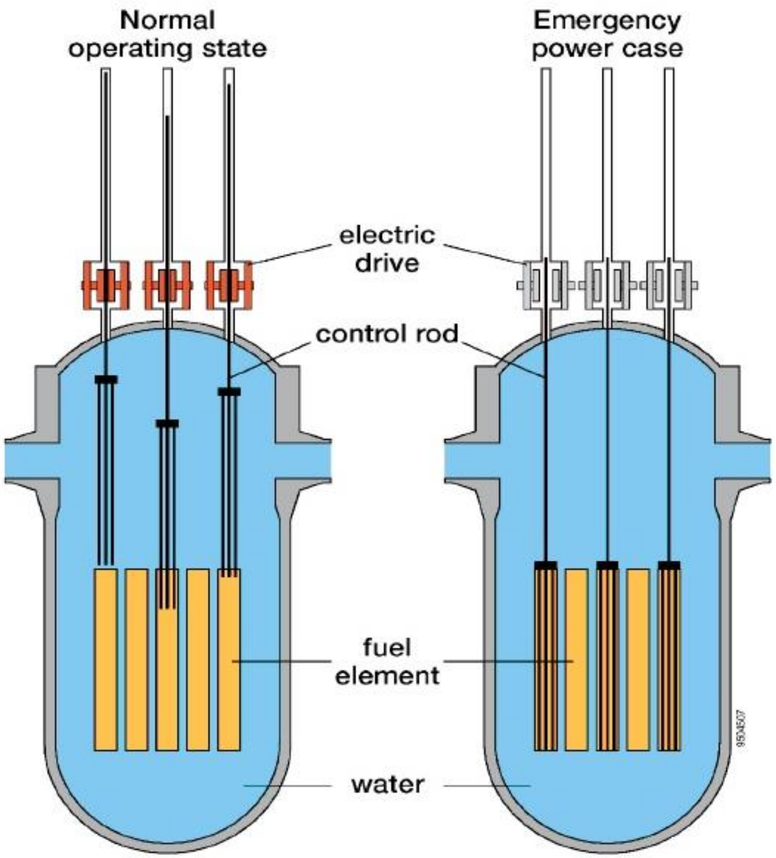
Fail Safe Design

Definition:

- Design ensuring that in the event of a failure the system behaves in a way that will cause no harm

Example:

- To shutdown the reactor the control rods have to be inserted into the reactor core
  - Normally the control rods are held and moved by electric drives
  - In the event of a power failure, the control rods fall into the core under gravity



Design Considerations on Safety System

What else?

- Design basis accidents
  - 30 minutes criterion
    - No operator action required during the first 30 minutes of an accident
- Internal and external hazards
- Appropriate instructions
  - Operating and maintenance instruction (normal operation and operational occurrences)
  - For incidents and accidents:
    - Event sequence based workflow instruction (operational occurrences and design basis accidents)
    - Protection goal oriented instructions (other accidents)
  - Internal accident management measures (severe accidents)
  - Off-site emergency response measures (severe accidents)
- Evaluation of the operating experience
- Systematic safety assessments (on a regular basis, e.g. every 10 years)
  - Deterministic safety assessments + probabilistic safety assessments

Internal and External Hazards

Internal hazards

- Fire
- Explosion
- Flooding
- Missiles
  (e.g. from high energy components)
- Heavy load drop
  (e.g. from structural failures
  or crane failures)

External Hazards

Natural Hazards

- Earthquake
- Flooding
- Storm
- Lightning
- Other meteorological hazards

Man-made Hazards

- Explosion (off-site)
- Fire (off-site)
- Aviation accidents

Containment Systems

Containment systems are designed to prevent the release of radioactive material into the environment.

1. Fuel cladding

The fuel cladding is the first layer of protection around the nuclear fuel and is designed to protect the fuel from corrosion that would spread fuel material throughout the reactor coolant circuit. In most reactors it takes the form of a sealed metallic or ceramic layer. It also serves to trap fission products, especially those that are gaseous at the reactor's operating temperature, such as krypton, xenon and iodine. Cladding does not constitute shielding, and must be developed such that it absorbs as little radiation as possible. For this reason, materials such as magnesium and zirconium are used for their low neutron capture cross sections.

Containment Systems

2. Reactor vessel

The reactor vessel is the first layer of shielding around the nuclear fuel and usually is designed to trap most of the radiation released during a nuclear reaction. The reactor vessel is also designed to withstand high pressures.

3. Primary containment

The primary containment system usually consists of a large metal and concrete structure (often cylindrical or bulb shaped) that contains the reactor vessel. In most reactors it also contains the radioactively contaminated systems. The primary containment system is designed to withstand strong internal pressures resulting from a leak or intentional depressurization of the reactor vessel.

Containment Systems

4. Secondary containment

Some plants have a secondary containment system that encompasses the primary system. This is very common in BWRs because most of the steam systems, including the turbine, contain radioactive materials.

5. Core catching

In case of a full melt-down, the fuel would most likely end up on the concrete floor of the primary containment building. Concrete can withstand a great deal of heat, so the thick flat concrete floor in the primary containment will often be sufficient protection against the so-called China Syndrome. The Chernobyl plant didn't have a containment building, but the core was eventually stopped by the concrete foundation. Due to concerns that the core would melt its way through the concrete, a "core catching device" was invented, and a mine was quickly dug under the plant with the intention to install such a device.

Standby Gas Treatment

A standby gas treatment (SBGT) system is part of the secondary containment system. The SBGT system filters and pumps air from secondary containment to the environment and maintains a negative pressure within the secondary containment to limit the release of radioactive material.

Ventilation and radiation protection

In case of a radioactive release, most plants have a system designed to remove radioactivity from the air to reduce the effects of the radioactivity release on the employees and public. This system usually consists of containment ventilation that removes radioactivity and steam from primary containment. Control room ventilation ensures that plant operators are protected. This system often consists of activated charcoal filters that remove radioactive isotopes from the air.

Thank you