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Working Groups Meeting

08:30 October 20, 2009

SRF Linac Driven Subcritical Core

Safety Performance and Issues

Subcritical/Accelerator Interface and Safety Issues

Jim Cahalan

Basic Safety Objectives

- **Protect public health and safety**
  - **Reduce the risk from releases of radioactivity to acceptable levels**
  - **Comply with regulatory requirements and provide additional margin**
- **Protect plant worker health and safety**
  - **Provide a safe working environment and reduce risk of injury**
  - **Comply with regulatory requirements and promote worker protection**
- **Protect the environment**
  - **Provide a design that complies with all federal, state, and local requirements**
  - **Build, operate, and decommission the plant in a way that preserves environmental quality**
- **Protect the plant investment**
  - **Provide plant designs, equipment, and operating/maintenance practices to preserve investor equity and return reward**
  - **Maintain product quality and reliability**

Radiation Protection Mechanisms

- **Barriers**
  - **Contain radioactive materials and prevent human exposure or release to the environment**
- **Distance**
  - **Provide spatial margins to reduce the intensity of radiation exposure**
- **Time**
  - **Isolate radioactive material until it has decayed to a stable or less harmful state**

Safety Design

- **By design, the plant and all its systems are configured and constructed in a manner that assures safe, stable, and reliable operation while preserving protection mechanisms**
- **Engineered safety systems are provided to *prevent* development of conditions that can defeat the basic radiation protection mechanisms, and to *mitigate* the consequences of equipment failure or inappropriate operator actions**
  - **Inherent protection margins (No operator action or equipment activation needed) can be provided by selection of materials and arrangement of components**
- **The design principle of *defense in depth* is applied for important safety-related functions**
  - **Containment**
  - **Reactor shutdown**
  - **Residual heat removal**

Defense in Depth

- **Plant functions that are important to preservation of safety protection mechanisms are designed according to the *defense in depth* principle, which provides multiple layers of safety assurance**
  - **Level 1: Provide a conservative design with large safety margins that can be constructed and operated normally without challenges to safety limits**
  - **Level 2: Provide additional design features that protect against a single, unlikely fault (~once in the plant lifetime). (Limited damage, minor repair).**
  - **Level 3: Provide additional design features that protect against a single, extremely unlikely fault (not expected in the plant lifetime). (Extensive damage, major repair)**
- **Foreseen events at Levels 1, 2, and 3 are within the plant safety design basis, and the most demanding events are usually identified as *Design Basis Accidents (DBAs)***
  - **DBAs are analyzed and the results are documented in safety reports to verify safety margins for licensing**

Defense in Depth Safety Design Features

- **For key safety functions (maintain barriers, keep radioactivity at a distance, and provide time for recovery)**
  - **Multiple, diverse, and independent structures, systems, or components, each of which is capable of achieving the defined safety function**
- **Redundancy, diversity, and independence assure that not all safety function can be lost due to a single failure, either internal (equipment failure, operator action) or external (earthquake, fire, flood)**
- ***Safety grade*** **systems, components, and systems are designed and maintained to criteria that assure their reliable operation**
  - **Quality assurance, inspection, testing, repair, ...**
  - **Seismic, electrical supply, …**

Safety Design Features

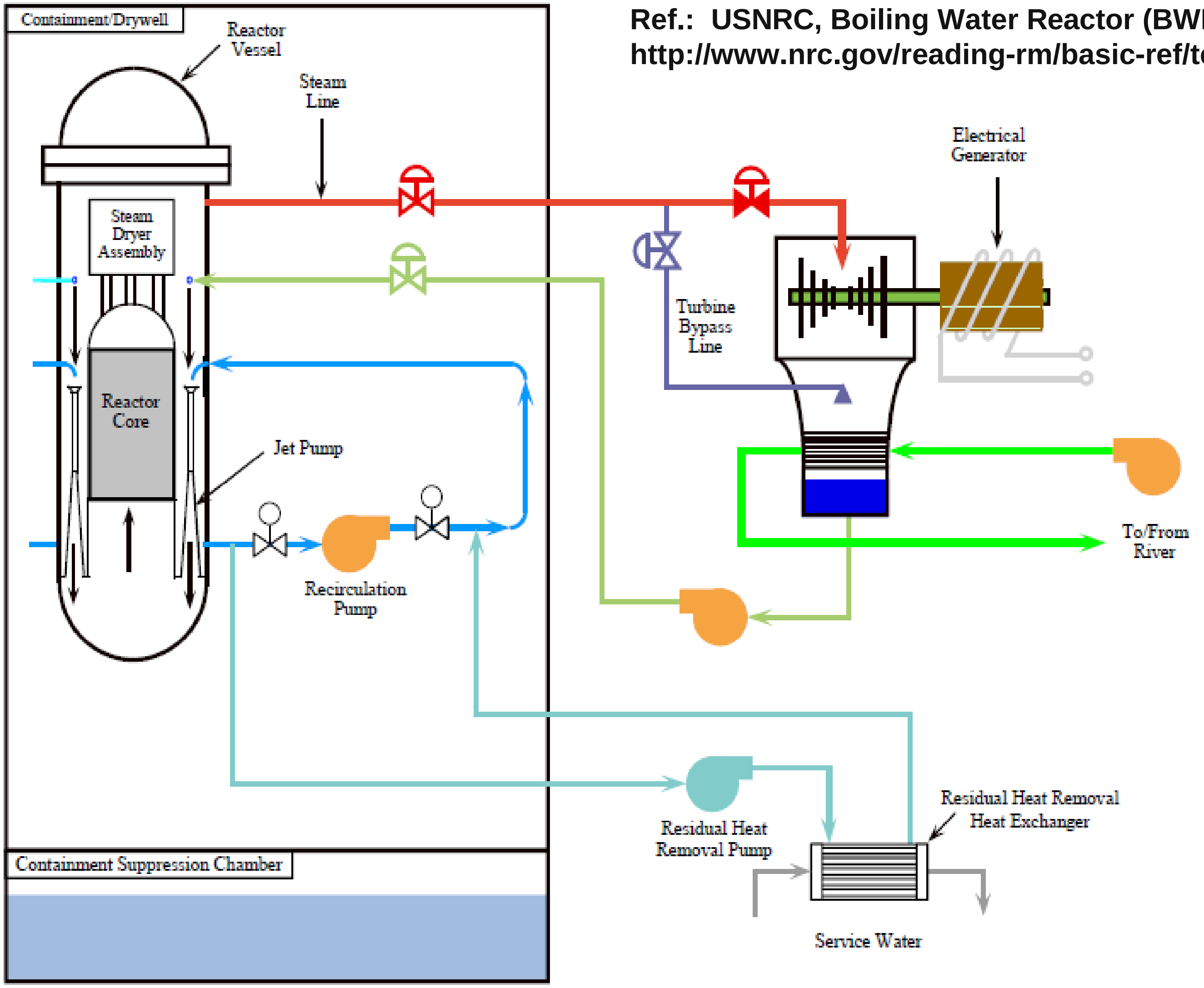
- Containment of radioactive material by multiple physical barriers
  - Fuel cladding
  - Primary coolant system boundary
  - Containment structure
- Reactor shutdown by multiple reactor control and protection systems
  - Primary shutdown system for startup, shutdown, reactor power changes, and power distribution management
  - Secondary shutdown system, always available for activation
- Residual heat removal by multiple heat transport paths and systems
  - Normal heat removal system (SG, condenser)
  - Dedicated shutdown heat removal systems (HXs, forced or natural circulation, from primary or secondary coolant, through vessel wall)

ADS Safety Design Issues

- **For reference, see Code of Federal Regulations, Title 10, Part 50, Appendix A (10CFR50, App. A) for General Design Criteria (GDC) applicable to commercial Light Water Reactors (LWRs)**
  - **Sets safety performance design requirements**
- **The case for subcritical reactor safety is often stated in terms of the role of decoupling reactivity and power, and the degree of subcriticality**
  - **In fact, the total safety case depends on many factors that include performance of containment, cooling, and control systems**
- **Residual decay heat requirements and design features for a subcritical system will be the same as for a critical system**
  - **Reactor cooling after the driving beam has been shut down**
  - **Both normal and safety-grade emergency shutdown cooling systems will be required**
- **Special requirements and design features for an ADS:**
  - **Containment**
  - **Reactor control and protection**

Boiling Water Reactor (BWR) Residual Heat Removal Systems

Ref.: USNRC, Boiling Water Reactor (BWR) Systems, http://www.nrc.gov/reading-rm/basic-ref/teachers/03.pdf

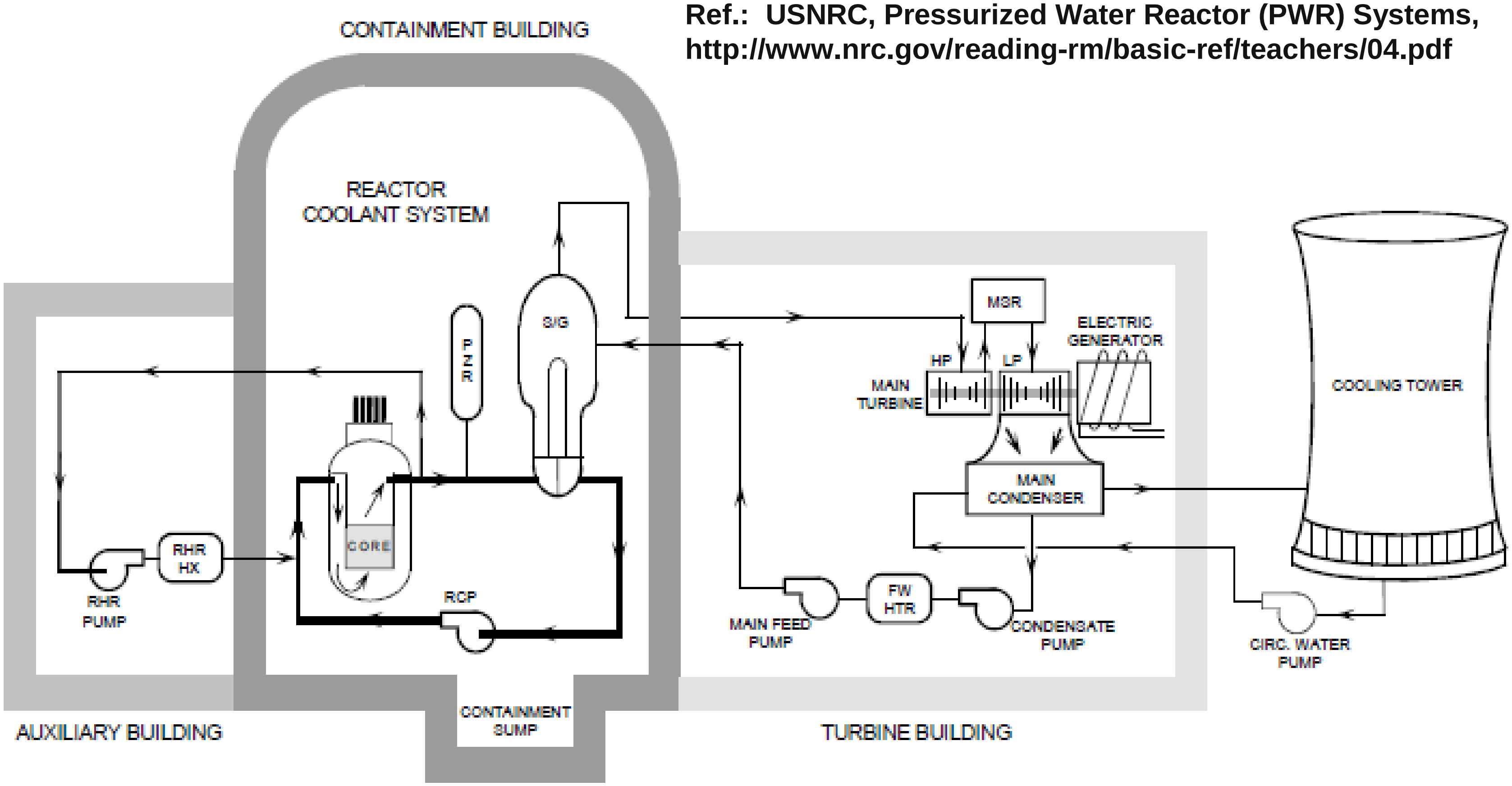


ADS Safety Design Issues: Containment

- **For an ADS, the driving beam must penetrate two of the three barriers normally in place to contain radioactive material**
  - **The containment building**
  - **The primary coolant system**
- **Design decisions are necessary to determine the interface configurations between the beam tunnel and the containment building boundary, and between the beam and the primary coolant system**
  - **Does the beam tunnel become part of the containment building?**
  - **Does the target become integral with the reactor coolant system?**
  - **Are the interfaces able to be inspected, tested, repaired?**

Pressurized Water Reactor (PWR) Containment Concept

Ref.: USNRC, Pressurized Water Reactor (PWR) Systems, http://www.nrc.gov/reading-rm/basic-ref/teachers/04.pdf



Boiling Water Reactor (BWR) Containment Concept

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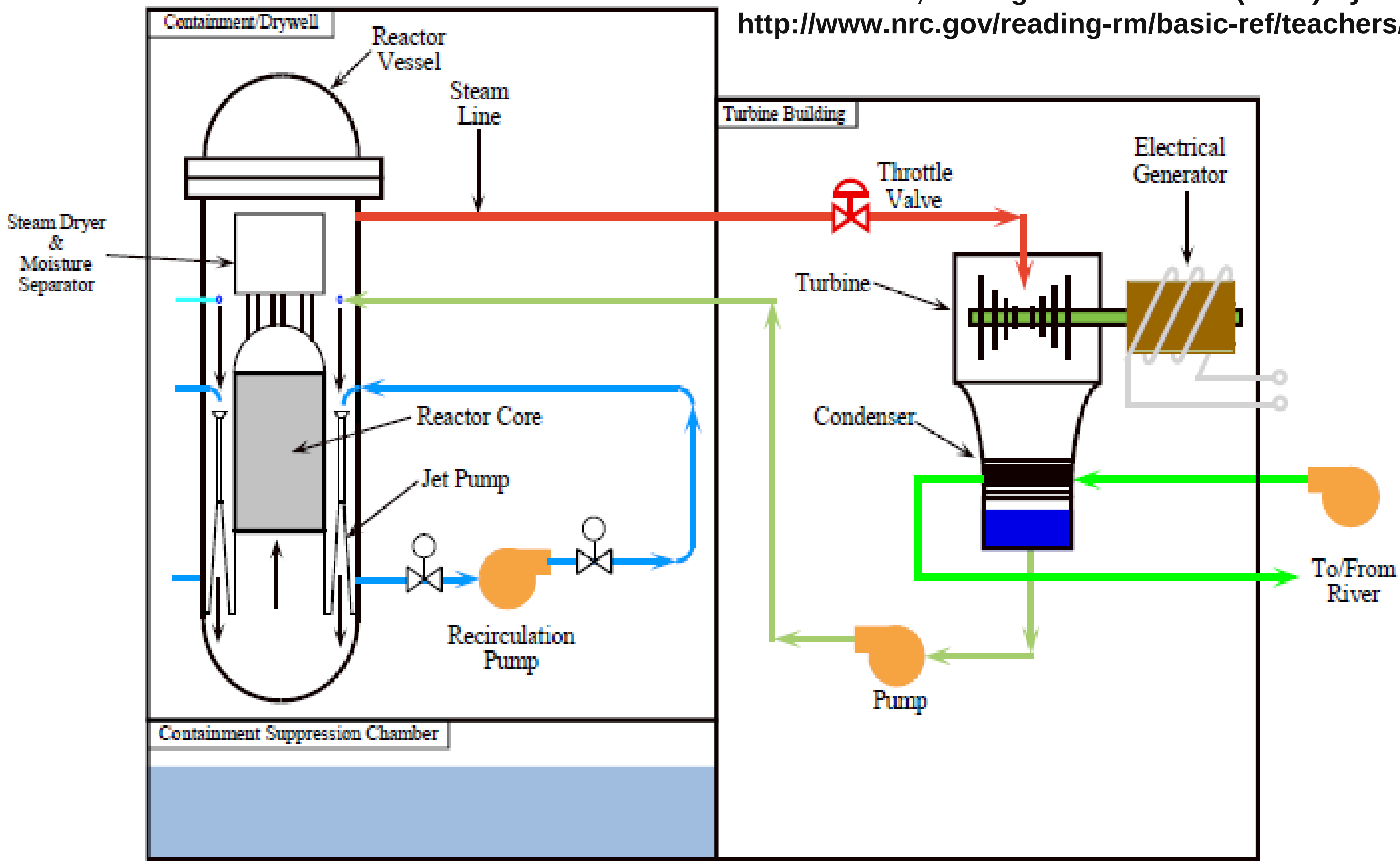

ADS Safety Design Issues: Reactor Control and Protection—1

- **For an ADS, the reactor control and shutdown functions focus on beam management and cooling systems operation**
  - **The normal reactor instrumentation for critical reactor reactivity control and protection will be used for beam management**
  - **Mechanisms are needed for controlled reactor start-up and shutdown, as well as emergency shut down**
- **The accelerator/reactor control interface is a two-way portal**
  - **A fault on the accelerator side (beam interruption) must be communicated to the reactor to allow normal shutdown**
  - **A fault on the reactor side must be communicated back to the accelerator to command beam shutdown (or diversion) to permit graceful termination of power production**
    - ***Terminate power deposition in the target and reactor***
    - ***Programmed reduction of reactor coolant flow***
    - ***Avoid thermal shocks in the reactor system***

ADS Safety Design Issues: Reactor Control and Protection—2

- **Past studies at ANL have highlighted the issue of frequent beam interruptions causing excessive thermal fatigue in reactor structures**
  - **Reactors are normally designed for one emergency shutdown per year (total of a few dozen or less in the life of the plant)**
- **10CFR50 Appendix A requires an inherent (passive) mechanism separate from the active systems for protection against external events that can suddenly increase reactor power (e.g. seismic motions, inlet temperature decrease, etc.)**
  - **In a critical system, prompt negative reactivity feedback is provided by the fuel Doppler effect**
  - **In a subcritical system, depending on the level of sub-criticality, the reactivity and power are uncoupled, and the fuel Doppler effect may not be effective**

Beyond-Design Basis Reactor Safety Considerations

- **Background: The level of the initial subcriticality is a design parameter**
  - **As the degree of subcritcality is reduced (operation closer to critical), the reactor multiplication increases and greater reactor power is achieved for a given beam power**
- **For fast spectrum subcritical reactors, the issue of beyond-design basis safety (multiple fault initiators, severe accident prevention and consequence mitigation) is as relevant as for critical reactors**
  - **Fast reactors (critical and subcritical) normally operate with many (five or more) critical masses to promote efficient neutronic performance (transmutation)**
  - **Fuel reconfigurations in severe accidents with fuel melting and compaction can result in reactivity additions that exceed the initial subcriticality**

Summary and Conclusion

- **Safety-related design criteria and features for nuclear reactors are well defined**
  - **Mature regulation status for commercial nuclear power reactors**
- **ADS subcritical reactors will be subject to the same top level criteria and regulations**
  - **Design solutions will be needed to address containment, reactor protection and control, and decay heat removal requirements**
- **The accelerator/reactor interface and safety issues can be resolved within the normal engineering design process, subject to the usual performance and cost trade-off assessments**
  - **No ‘show stoppers’**