ACR Sequence of Key Events

Massimo Bonechi
ACR Safety Engineering
Presented to the Nuclear Regulatory Commission
Washington, DC
May 15-16, 2003

AECL
TECHNOLOGIES INC.

Presentation Outline

- Classification of Design Basis events.
- Event sequence for representative Class 1 events.
- Event sequence for representative Class 2 events.
- Event sequence for representative Class 3 events.

Classification of Design Basis Events

- Three classes of design basis events in addition to states of normal operation
- Class 1: Events of Moderate Frequency
  - Incidents which may occur during a calendar year for a particular plant
- Class 2: Infrequent Events
  - Incidents which may occur during the lifetime of a particular plant
- Class 3: Limiting Events
  - Faults that are not expected to occur but are postulated because of their potentially significant consequences

Examples of Design Basis Events

Class 1: Events of Moderate Frequency

- Failure of Pressure or Inventory Control in the Reactor Coolant System (RCS)
- Failure of Secondary Circuit Pressure Control
- Failure of Reactor Power Control
- **Loss of Class IV Power (Station normal AC power supply)**
- Single Reactor Coolant Pump Trip
- Moderator Events (except pipe ruptures)
- Loss of Normal Steam Generator Feedwater Flow.

Examples of Design Basis Events

Class 2: Infrequent Events

- Pressure Tube Failure (Calandria Tube Intact)
- **Small Loss-of-Coolant Accident (LOCA)**
- **End Fitting Failure**
- Off-Stagnation Feeder Break
- Moderator Events (pipe ruptures)
- Partial Single Channel Flow Blockage
- Steam Generator Tube Rupture.

Examples of Design Basis Events

Class 3: Limiting Events

- **Pressure Tube/Calandria Tube Rupture**
- **Large LOCA**
- **Main Steam Line Break (Inside Containment)**
- Reactor Coolant Pump Seizure.

Loss Of Class IV Power

1. All reactor RCS pumps trip.
2. The steam generator main feedwater pumps trip:
   - Temporary loss of make-up to the steam generators.
3. The primary coolant flow decreases because of pump rundown:
   - Power-to-flow mismatch causes an increase in the reactor coolant temperature and pressure; and
   - Opening of the RCS liquid relief valves is initiated.
4. The turbine trips due to a loss of condenser vacuum:
   - Condenser steam discharge valves (CSDV's) are unavailable.

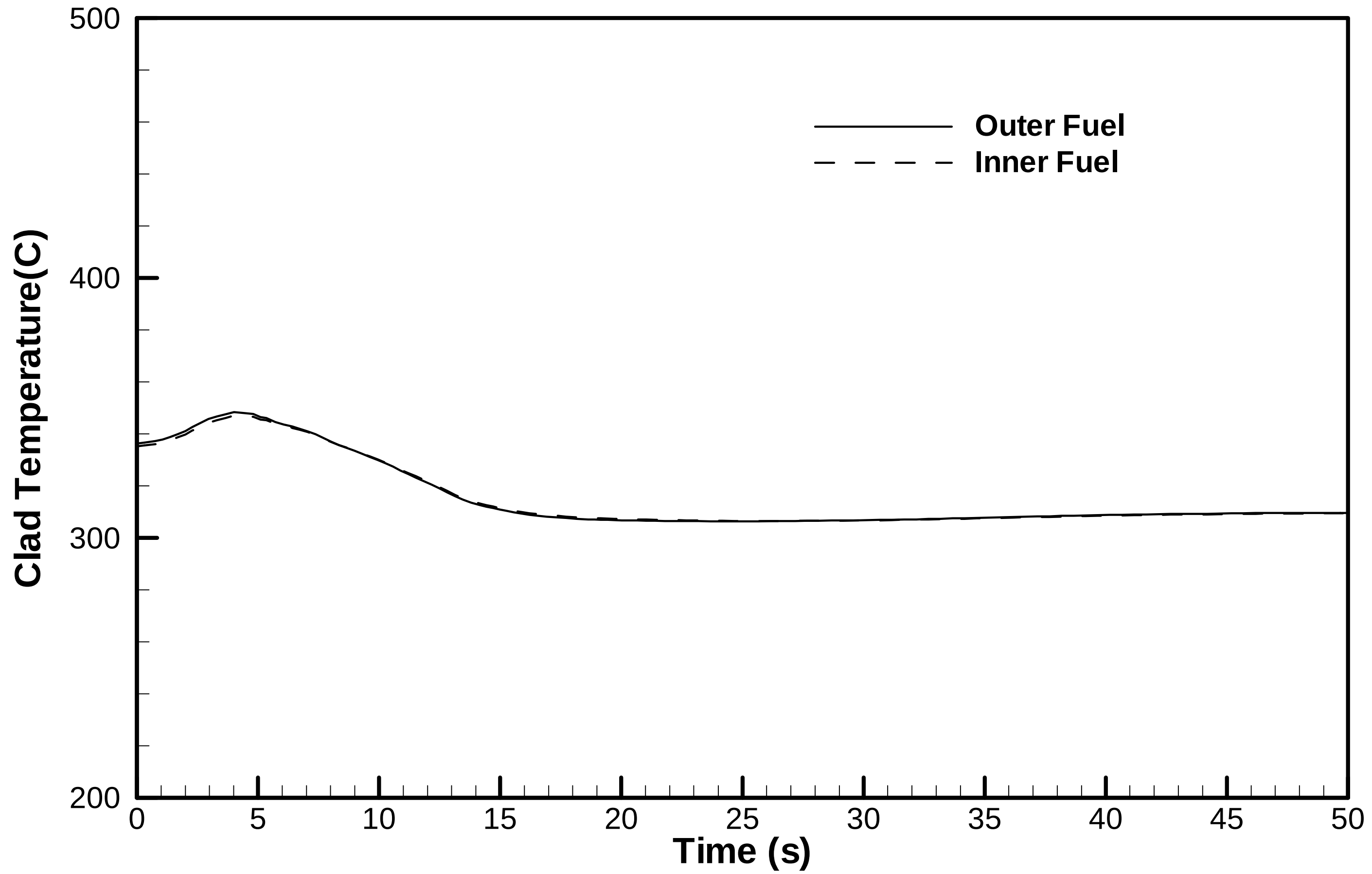
Loss Of Class IV Power

5. Pressurizer heaters fail off
6. Reactor trip initiated on SDS1 (gravity-drop rods) or on SDS2 (gadolinium nitrate injection into moderator) :
   – High pressure;
   – Low flow.
7. Main steam safety valves (MSSV's) open to prevent overpressure in the steam generators and reject the decay heat to the atmosphere:
   – Atmospheric Steam Discharge Valves (ASDV's) are assumed unavailable

Loss Of Class IV Power

8. Feedwater is maintained to the steam generators by the auxiliary feedwater pumps powered from the Class III electrical system (diesel-generators)
9. Indefinite heat sink is provided by the Long Term Cooling system

Loss Of Class IV Power



Typical clad temperature profile during a loss of Class IV power.

Loss Of Class IV Power

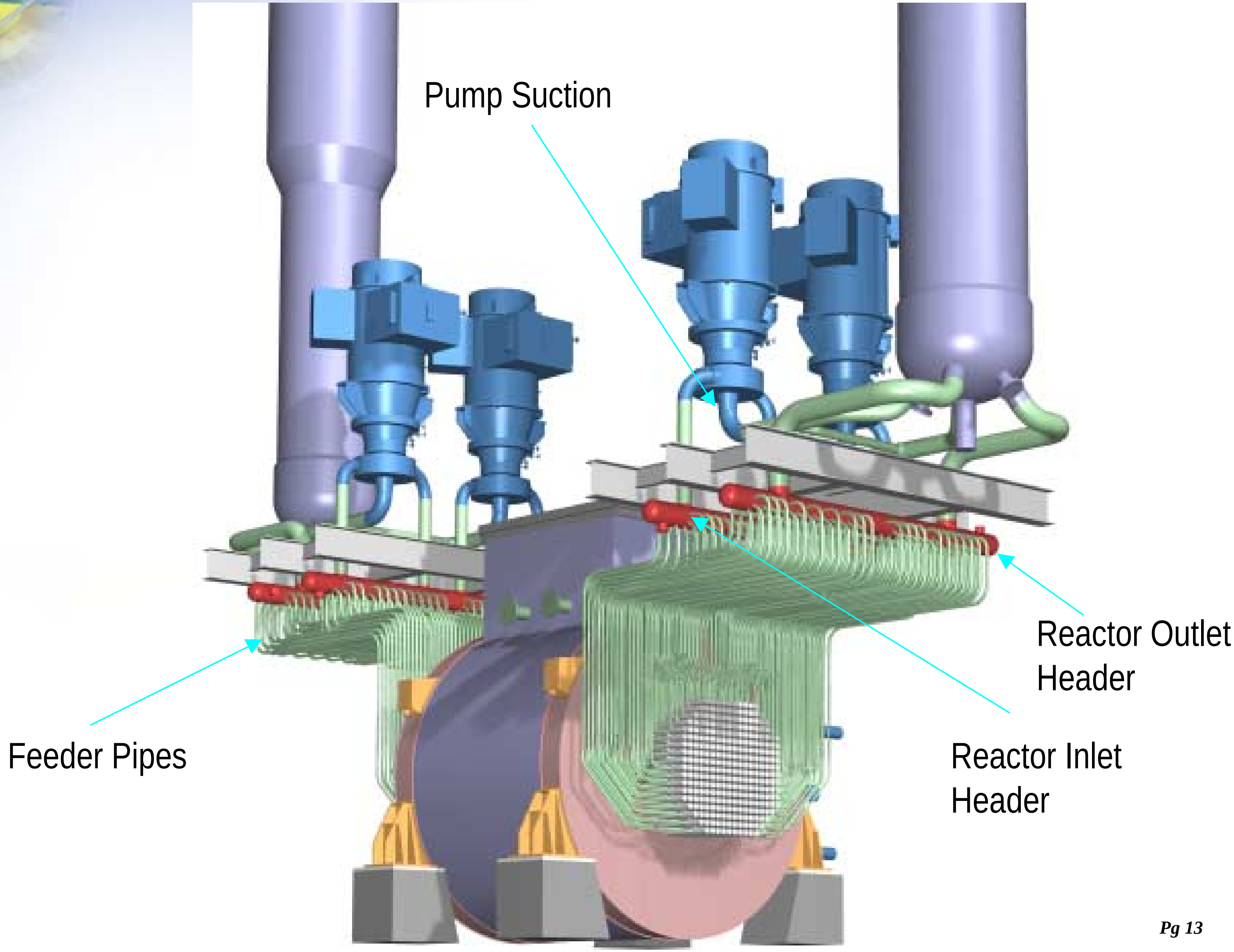
Event and System Response	Time (s)
Class IV power is lost RCS pumps begin rundown Feedwater pumps begin rundown Steam flow to turbine ramped down Pressurizer heaters fail off	**0.0**
RRS stepback on RCS high pressure (not credited)	**~3**
Reactor trip initiated	**~3.5**

Examples of Design Basis Events

Class 2: Infrequent Events

- Pressure Tube Failure (Calandria Tube Intact)
- **Small LOCA**
- **End Fitting Failure**
- Off-Stagnation Feeder Break
- Moderator Events (pipe ruptures)
- Partial Single Channel Flow Blockage
- Steam Generator Tube Rupture.

Reactor Coolant System



Small Break LOCA

1. A small break discharges coolant into containment:
   – The largest small break is defined as any RCS pipe break equivalent to the cross sectional area of the largest feeder pipe (equivalent to a 2.5% reactor inlet header break).
2. Normal reactor coolant makeup system attempts to maintain nominal conditions in the RCS:
   – If the break size is beyond capacity, RCS inventory decreases and system begins to depressurize.
3. Containment pressure and temperature increase:
   – Heat transfer to wall surfaces and local air coolers;
   – High pressure or high activity in containment initiates containment isolation.

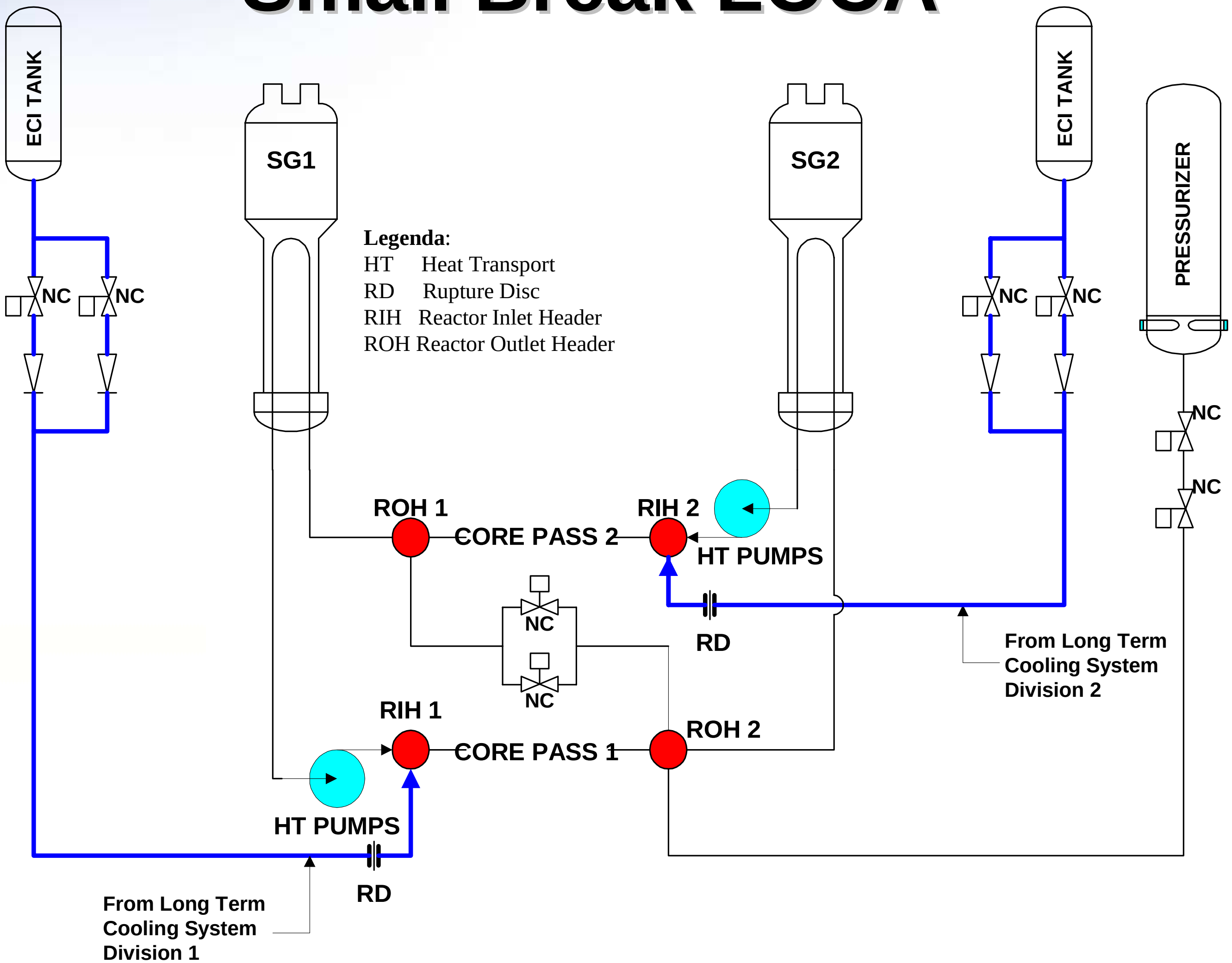
Small Break LOCA

4. RCS depressurization causes voiding in the core:
   - Reactor regulating system (RRS) tries to maintain reactor power;
   - If RRS cannot maintain power, power decreases.
5. The reactor trips on:
   - High containment pressure, RCS low flow, RCS low pressure.
6. RCS pressure and temperature decrease rapidly.

Small Break LOCA

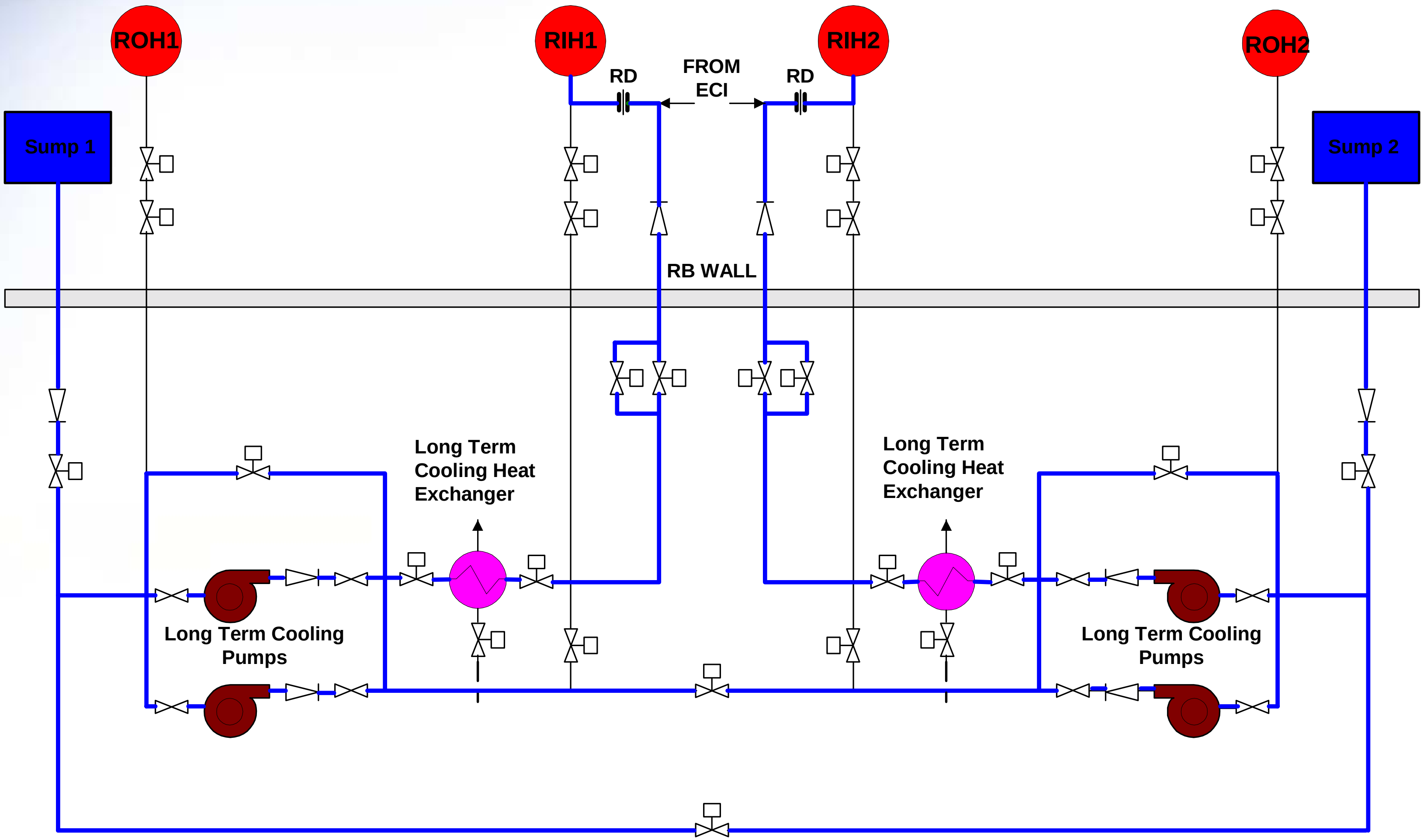
7. Emergency Coolant Injection (ECI) system is initiated:
   - Depressurization of the RCS generates LOCA signal;
   - Steam Generator crash cool (automatic depressurization) is initiated;
   - Valves in the large outlet header interconnect pipe open;
   - High-pressure injection valves open;
   - Rupture discs burst open at a set pressure differential (0.52 MPa);
   - High pressure injection flow begins and continues until high pressure tanks nearly empty; and
   - High pressure injection valves close and low pressure long term cooling is initiated.
8. Long Term Cooling (LTC) system maintains the RCS inventory and provides fuel cooling.

Small Break LOCA



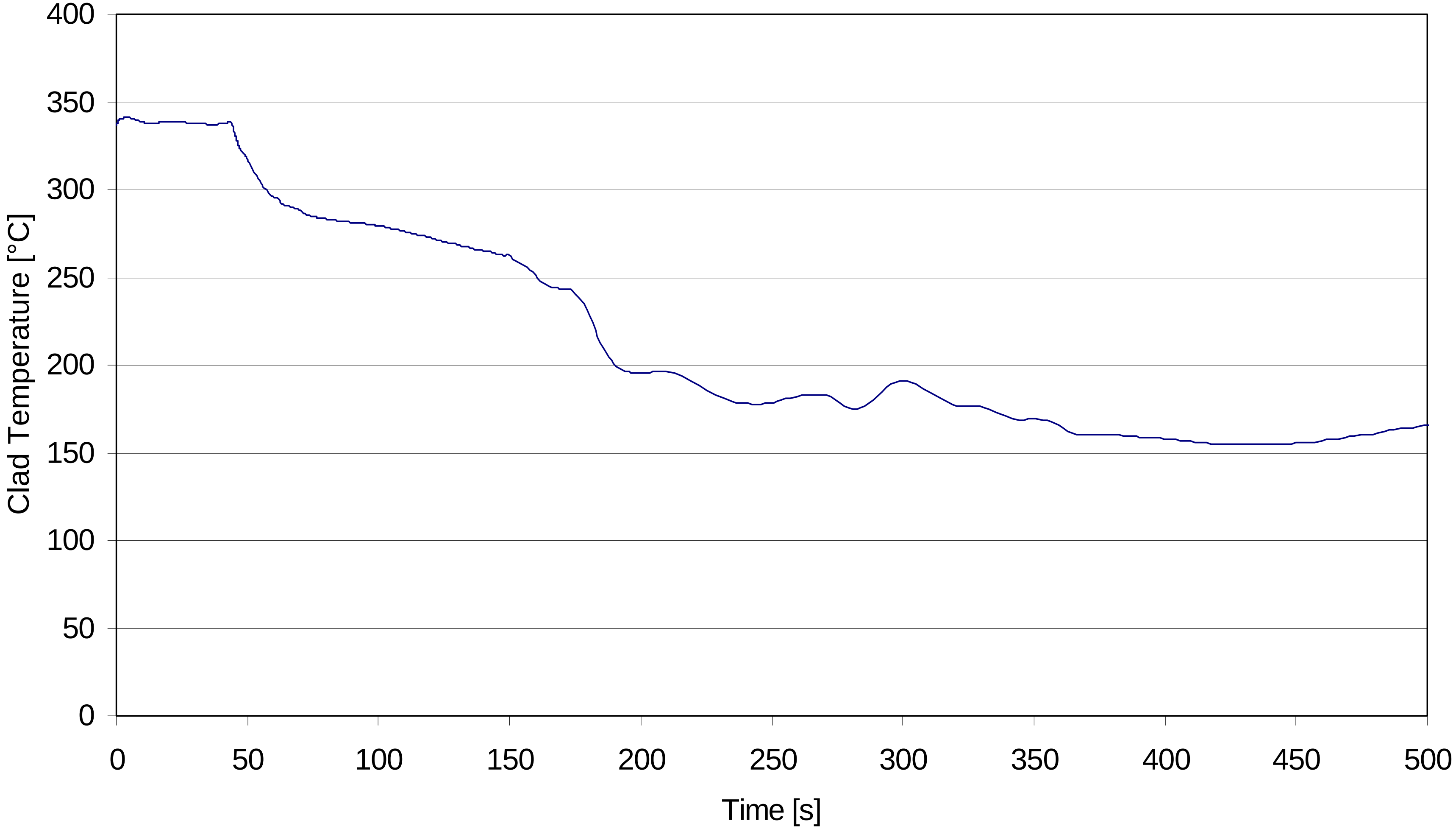
Emergency Coolant Injection System

Small Break LOCA



Long Term Cooling System

Small Break LOCA

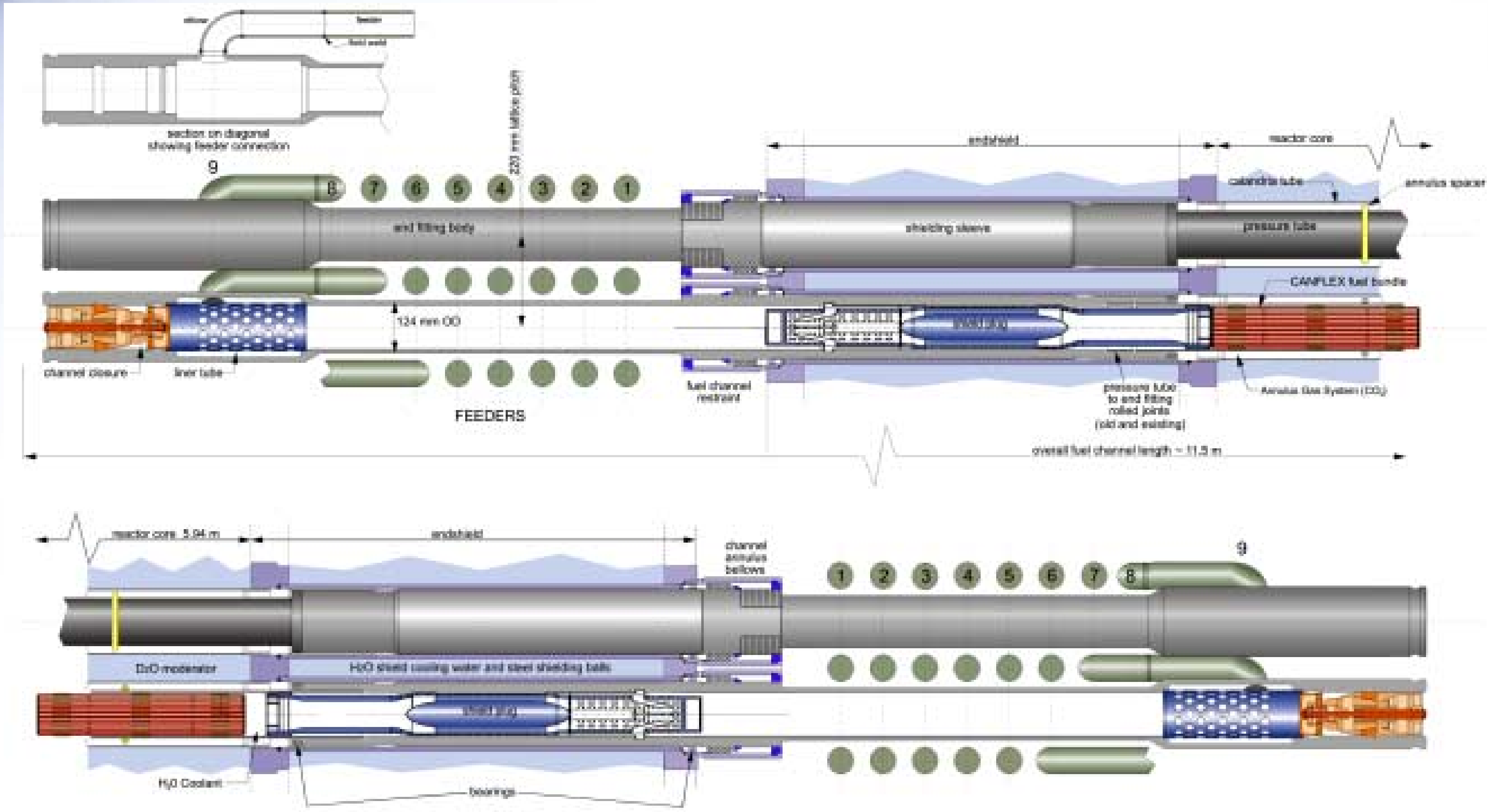


Typical clad temperature profile during a small break LOCA.

Small Break LOCA

Event and System Response	Time (s)
Break occurs	**0.0**
High containment pressure signal	**<45**
Reactor trip initiated	**~45**
LOCA signal	**~60**
SG crash cool (automatic depressurization) initiated	**~90**
ECI rupture discs open	**~150**
ECI injection stops and long term cooling system valved in	**~630**

End-Fitting Failure

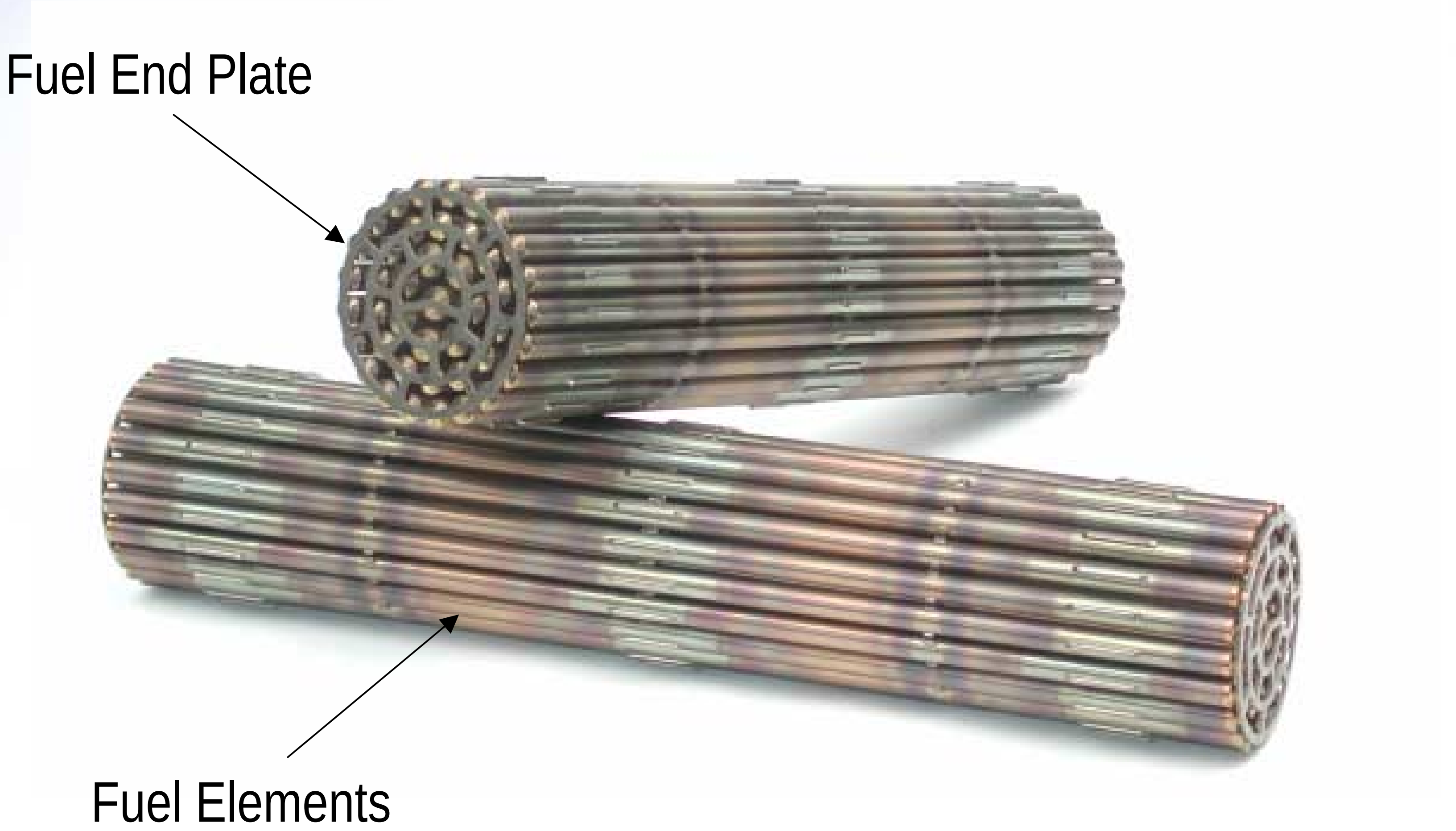


ACR - Fuel Channel

End-Fitting Failure

1. A complete severance of an end-fitting occurs in one of the fuel channels.
2. All fuel bundles are ejected from the channel.
3. The fuel bundles become damaged as they land in the fuelling machine vault.
4. Some elements separate from the end plates and could break into pieces.

End-Fitting Failure



End-Fitting Failure

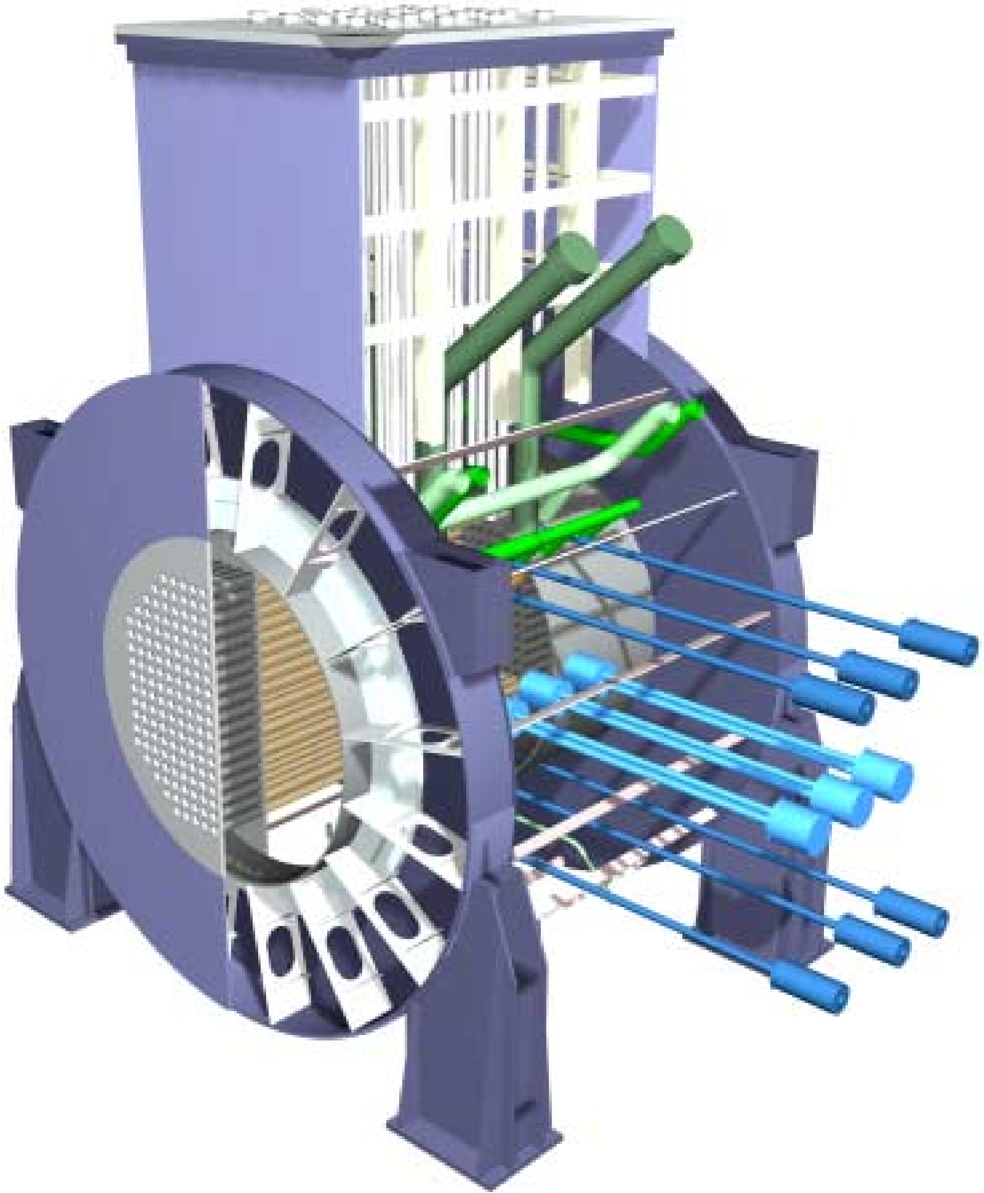
5. The rest of the unaffected channels behave the same as during a small break LOCA.
6. Fission products from the damaged fuel are released into the vault.
7. The amount of fission product release depends upon:
   – The amount of damage to the fuel (size of fuel fragments);
   – The degree of fuel heatup; and
   – The rate of UO_2 oxidation.

Examples of Design Basis Events

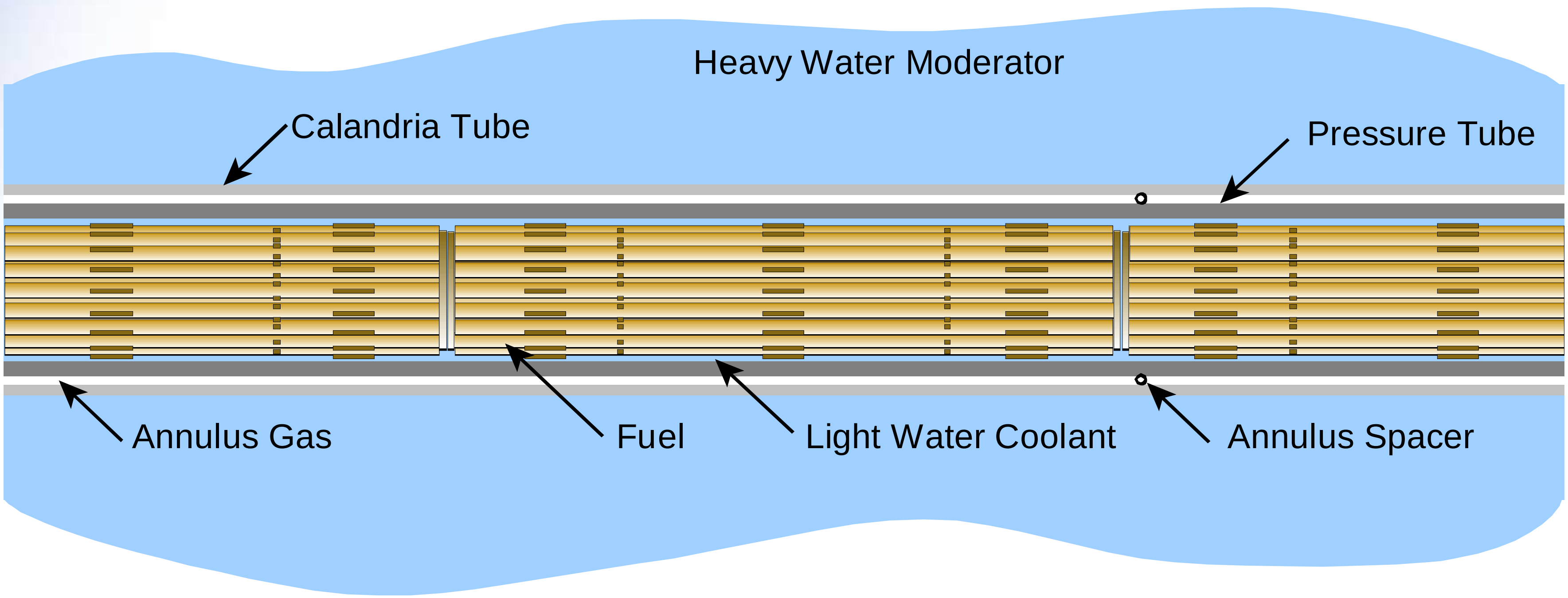
Class 3: Limiting Events

- **Pressure Tube/Calandria Tube Rupture**
- **Large LOCA**
- **Main Steam Line Break (Inside Containment)**
- Reactor Coolant Pump Seizure.

In-Core Breaks



Fuel Channel



In-Core Breaks

1. A break occurs in a pressure tube and leads to its rupture.
2. The surrounding calandria tube fails:
   - If the calandria tube does not fail, the bellows will fail;
   - For bellows failure, the event is similar to a small out-of-core LOCA.
3. The fuel in the broken channel is ejected into the calandria vessel. Fission product release can occur into the moderator.

In-Core Breaks

4. The moderator pressure and temperature increase as primary coolant is ejected into the calandria vessel:
   – The reactor coolant light water introduces negative reactivity and reactor power begins to decrease.
5. The moderator pressure increase causes the calandria relief ducts to rupture:
   – RCS/moderator liquid discharged into containment;
   – Fission products discharged into containment with the water.
6. The pressure and inventory control system responds trying to maintain nominal conditions:
   – For in-core breaks, with the calandria tube rupture, there will be a net RCS inventory loss and depressurization.

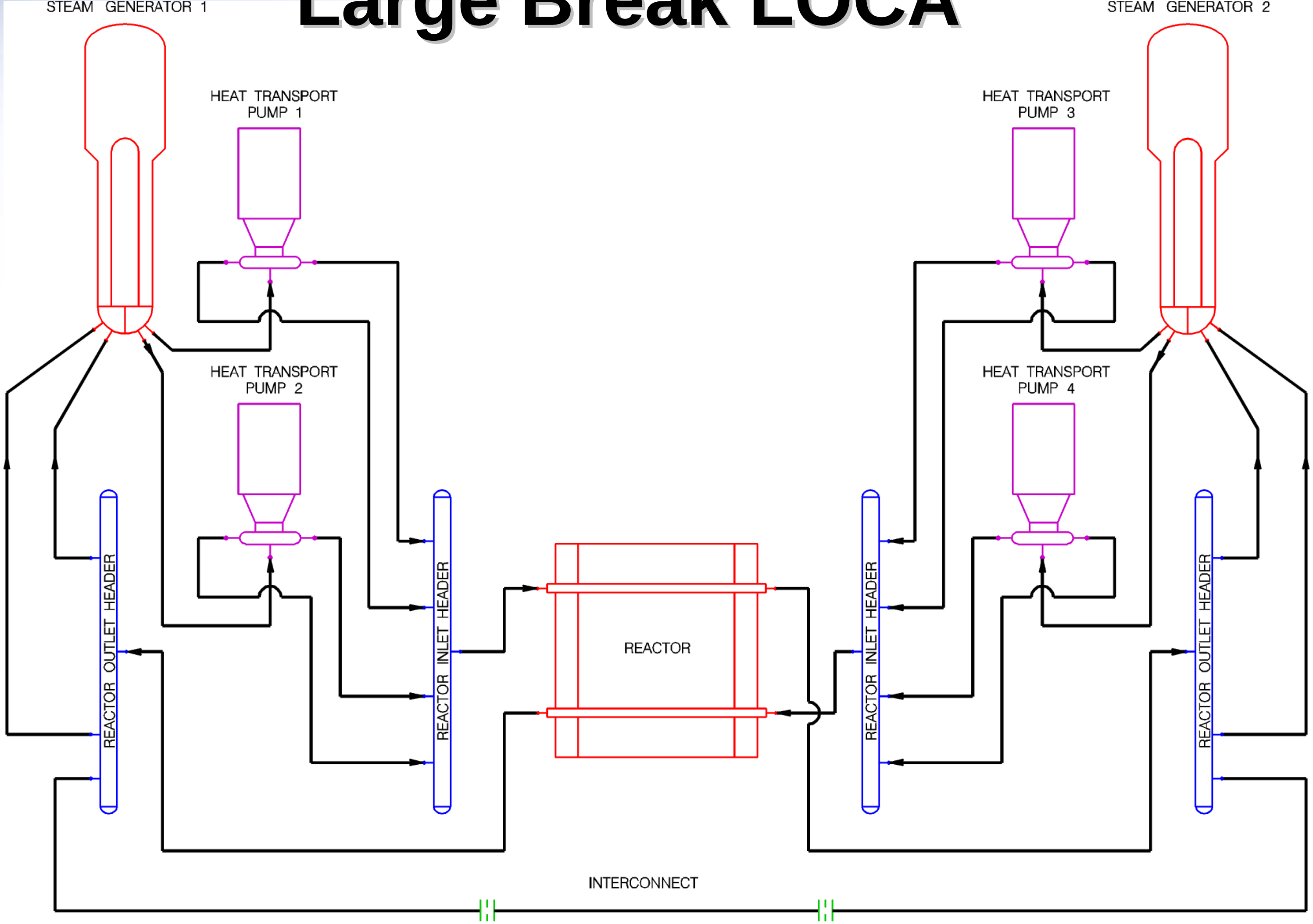
In-Core Breaks

7. The RRS responds to maintain reactor power until reactor trip is initiated.
8. The reactor trips on:
   - Moderator high level, RCS low pressure
9. RCS pumps run until pump trip is initiated.
10. The ECI system is initiated.
11. After ECI operation the Long Term Cooling system maintains the RCS inventory and provides fuel cooling.

In-Core Breaks

Event and System Response	Time (s)
Break occurs	**0.0**
Reactor trip	**~200**
LOCA signal	**~230**
SG crash cool (automatic depressurization) initiated	**~260**
ECI Initiation	**~330**

Large Break LOCA



Schematic of the ACR RCS .

Large Break LOCA

1. A large break is postulated to occur in a large diameter pipe (reactor inlet header, reactor outlet header, or pump suction pipe), discharging coolant into containment.
2. The pressure and temperature of the containment atmosphere increase.
3. The depressurization causes coolant voiding:
   - RRS tries to compensate to keep power constant;
   - For breaks in the large break spectrum, the reactor power will decrease.
4. Reactor trip is initiated:
   - High containment pressure, RCS low flow, RCS low pressure

Large Break LOCA

5. Containment isolation is initiated on high containment pressure signal
6. The RCS loses inventory and depressurizes at a rate dependent upon the break size and location.
7. The RCS flow decreases faster in the core pass downstream of the break. If the break is large enough, the flow will reverse in that pass.

Large Break LOCA

8. For a very specific break size in the RIH, the flow becomes very low as the break upstream of the core pass balances the pumps. This can lead to flow stagnation within the channels resulting in high fuel and pressure tube temperatures.
9. Conservatively no credit is given to the normal reactor coolant makeup

Large Break LOCA

10. When the RCS pressure falls below a specified set-point, ECI system is initiated:
    - Depressurization of the RCS generates LOCA signal;
    - Steam Generator crash cool (automatic depressurization) is initiated;
    - Valves in the large outlet header interconnect pipe open;
    - High-pressure injection valves open;
    - Rupture discs burst open at a set pressure differential (0.52 MPa);
    - High pressure injection flow begins and continues until high pressure tanks nearly empty; and
    - High pressure injection valves close and low pressure long term cooling is valved in (the LTC pumps start on a LOCA signal).

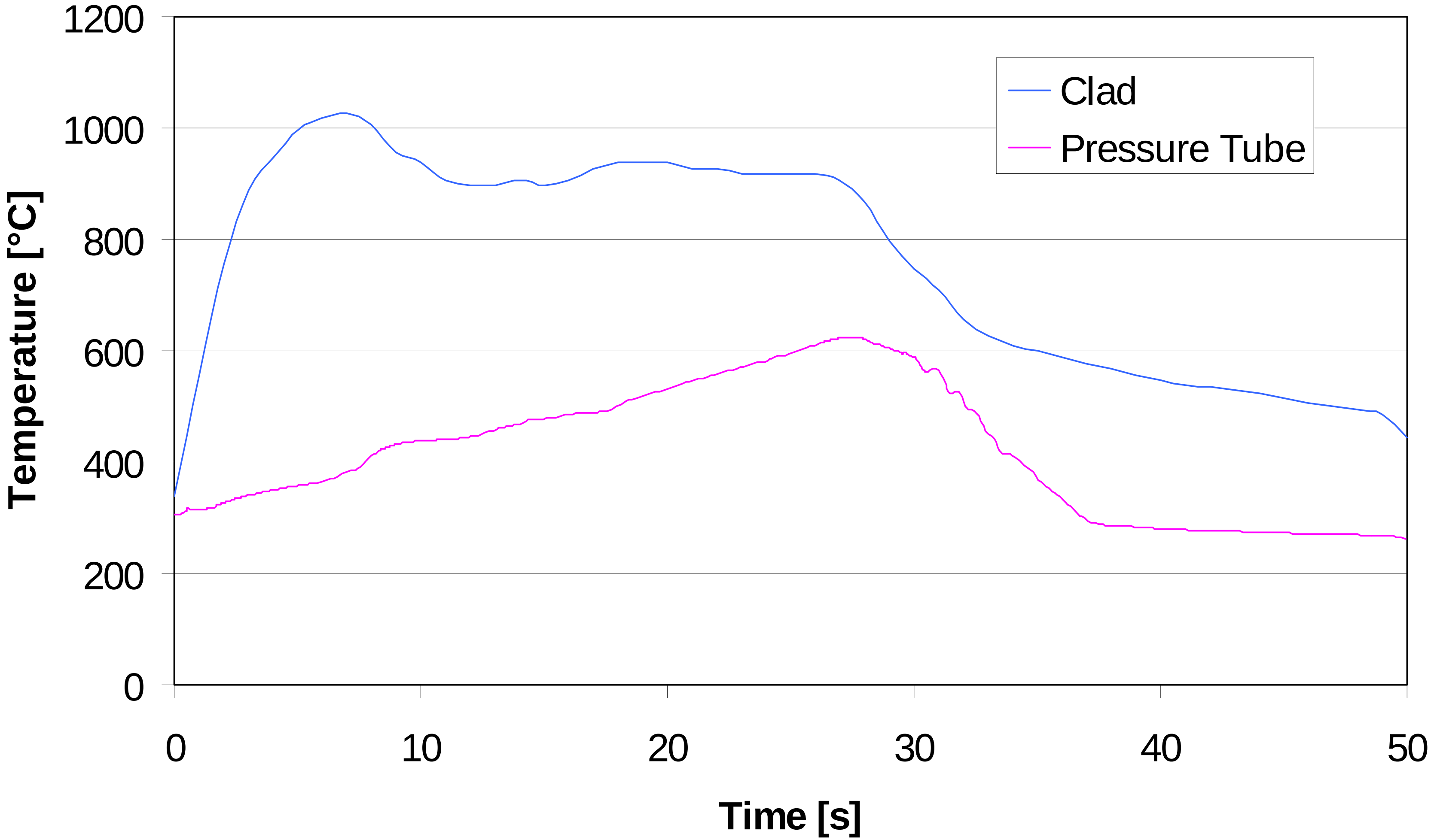
Large Break LOCA

11. After ECI injection and steam generator crash cool, the fuel and pressure tube temperatures decrease.
12. If there are fuel failures, some fission products are released into the coolant, are transported into containment through the break and can become airborne. Mechanisms of fission product removal from the containment atmosphere include plate-out on the walls and internal surfaces, and entrainment in the discharged reactor coolant.

Large Break LOCA

13. Long term cooling system maintains the RCS inventory and provides fuel cooling.
14. The reactor building pressure continues to decrease, primarily due to the energy removed by the accident qualified local air-coolers.

Large Break LOCA

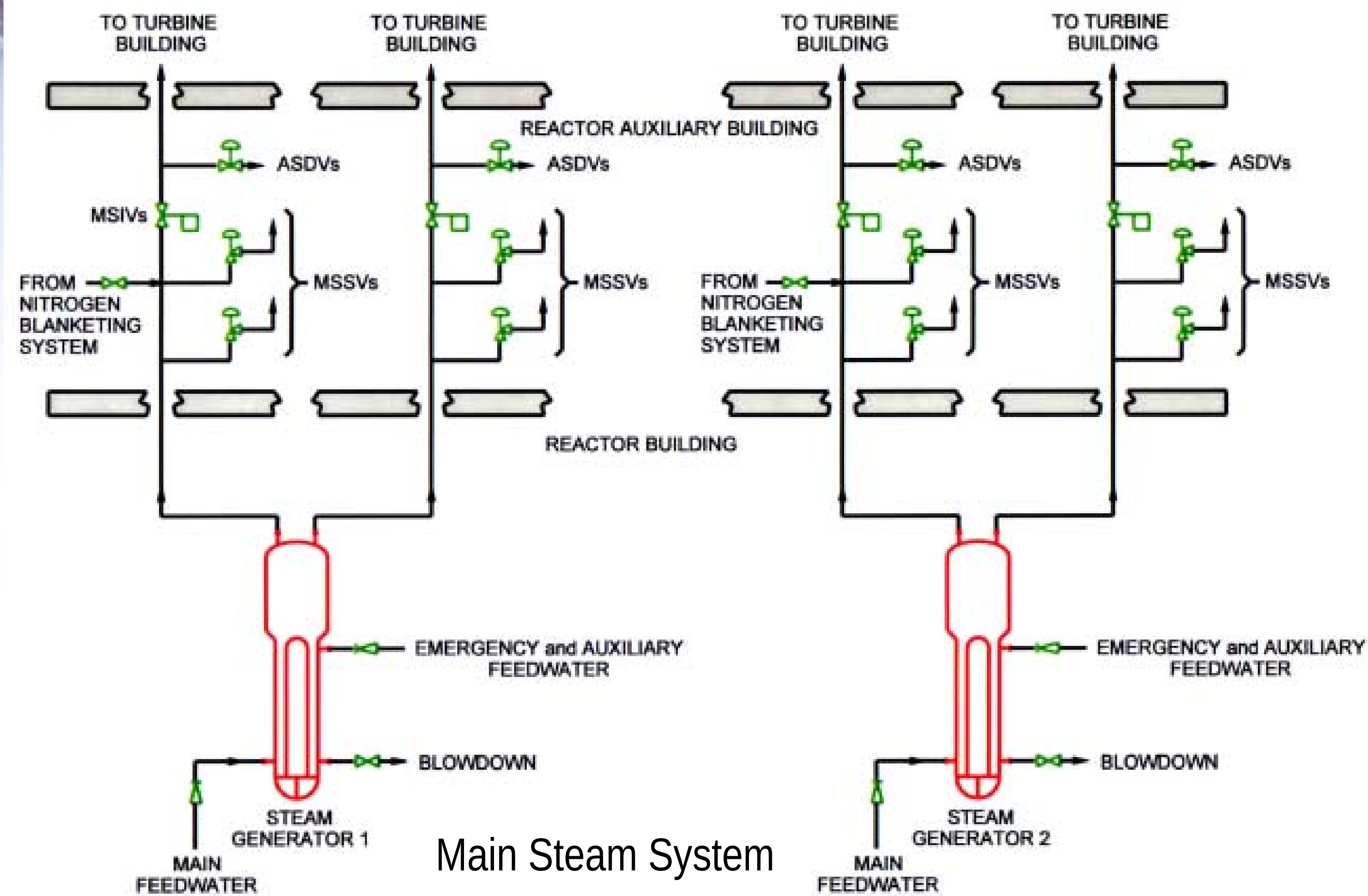


Typical clad and pressure tube temperature profile during large stagnation break LOCA.

Large Break LOCA

Event and System Response	Time (s)
Break occurs	**0.0**
Reactor trip initiated	**<2.0**
LOCA signal	**<3.0**
Crash cool (automatic depressurization) initiated	**~35**
ECI Initiation	**~40**
LTC starts	**~200**

Main Steam Line Break



Main Steam System

Main Steam Line Break

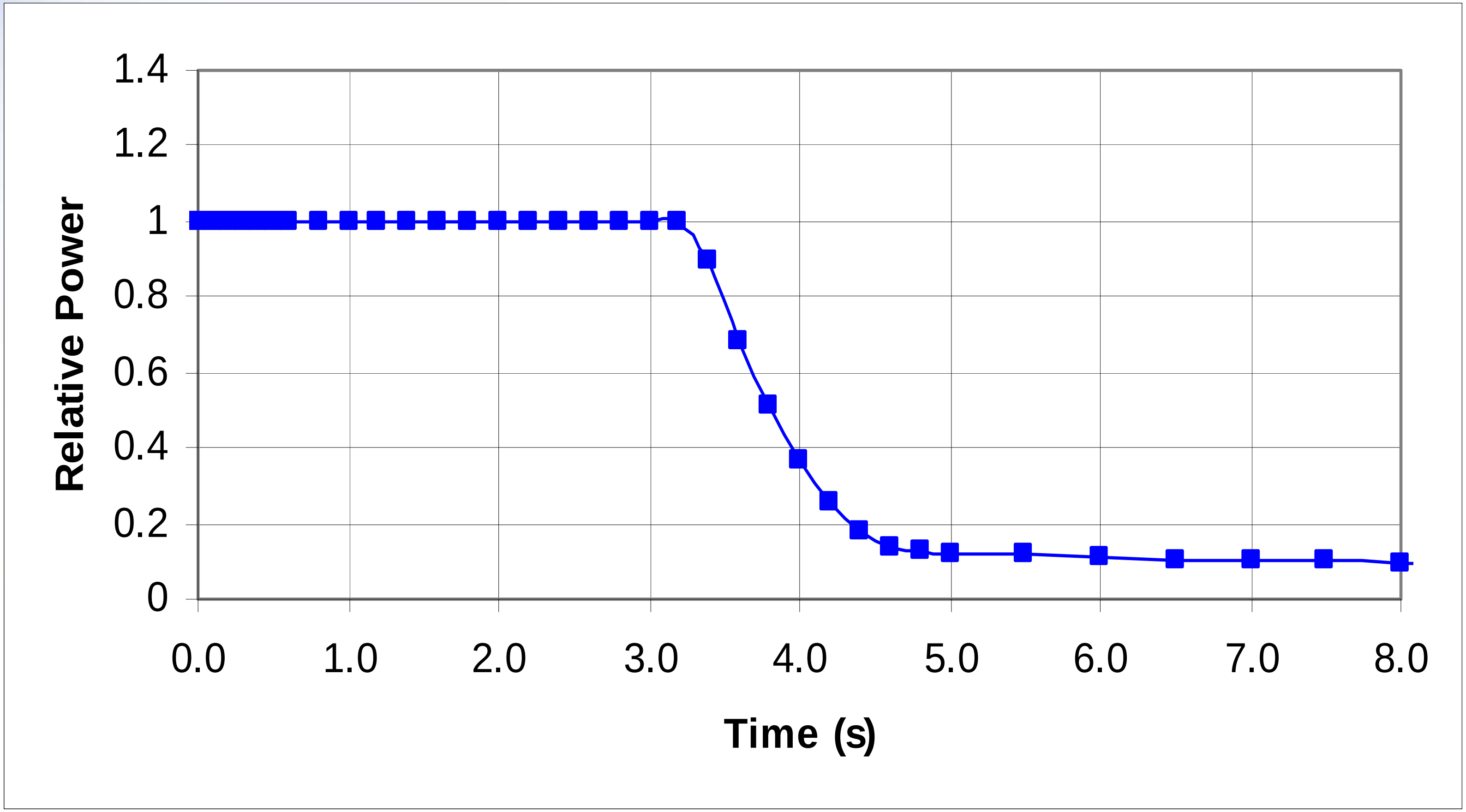
1. A large break in one of the main steam lines is postulated to occur inside the reactor building.
2. The rapid discharge of steam causes the pressure and temperature of the reactor building atmosphere to rapidly increase.

Main Steam Line Break

3. Immediately after the failure of the steam line, the flow rate through the corresponding steam generator increases:

   - Two phase flow is discharged into containment;
   - Steam generator level swells, and a turbine trip is initiated if the steam generator level becomes too high;
   - Eventually, the steam generators depressurize, the steam separators become effective, and single phase steam is discharged into containment.

Main Steam Line Break



Reactor power transient during a main steam line break.

Main Steam Line Break

4. Prior to reactor trip, the power excursion is negligible and the RRS is able to maintain reactor power.
5. A reactor trip is initiated:
   - High containment pressure, RCS low pressure, and steam generator low level.
6. Main steam isolation valves (MSIV's) start to close.
7. After the closing of the MSIVs, the main steam safety valves will open due to overpressure:
   - Steam generated by the other steam generators is prevented from discharging into the containment.
8. After reactor trip, the RCS begins to cool and depressurize.

Main Steam Line Break

9. Within the early stages of the transient, the reactor building pressure is high:
   - The activity within the RCS is only due to normal operation (activation products and small amounts of tritium).
   - Since the quantity of fission/activation products is low, releases from the plant, and the consequent doses, will be very low.
10. As the steam generators depressurize, the total discharge rate starts to decrease:
    - Containment pressurization rate decreases;
    - Internal components (reserve water tank, steel and concrete structures) absorb the heat from the containment atmosphere;
    - The local air coolers remove heat from containment.

Main Steam Line Break

11. The steam generator heat sink continues to be supplied by the feedwater system
    - Backup feedwater supply is assured by the Emergency Feedwater System: gravity-driven supply of water from a reserve water tank located at the top of the reactor building.
12. The Long Term Cooling System provides an indefinite heat sink in the long term.

Main Steam Line Break

Event and System Response	Time (s)
Break occurs	**0.0**
Reactor trip initiated	**~3**

Conclusion

- Three classes of design basis events
- Representative sequences in each class have been outlined
- Two independent and diverse shutdown systems ensure fast and reliable reactor trip
- Emergency core cooling with Emergency Coolant Injection System and Long Term Cooling System maintains reactor coolant inventory and fuel cooling for LOCA
- Steam generator heat sink ensured by diverse means of supplying backup feedwater: auxiliary feedwater pumps and emergency feedwater system (gravity-driven)
- Long Term Cooling System provides indefinite heat sink
- Prompt containment isolation for LOCA

AECL

TECHNOLOGIES INC.