Single Channel Flow Blockage and Feeder Stagnation Breaks

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ACR Fuel and Fuel Channel Safety Analysis

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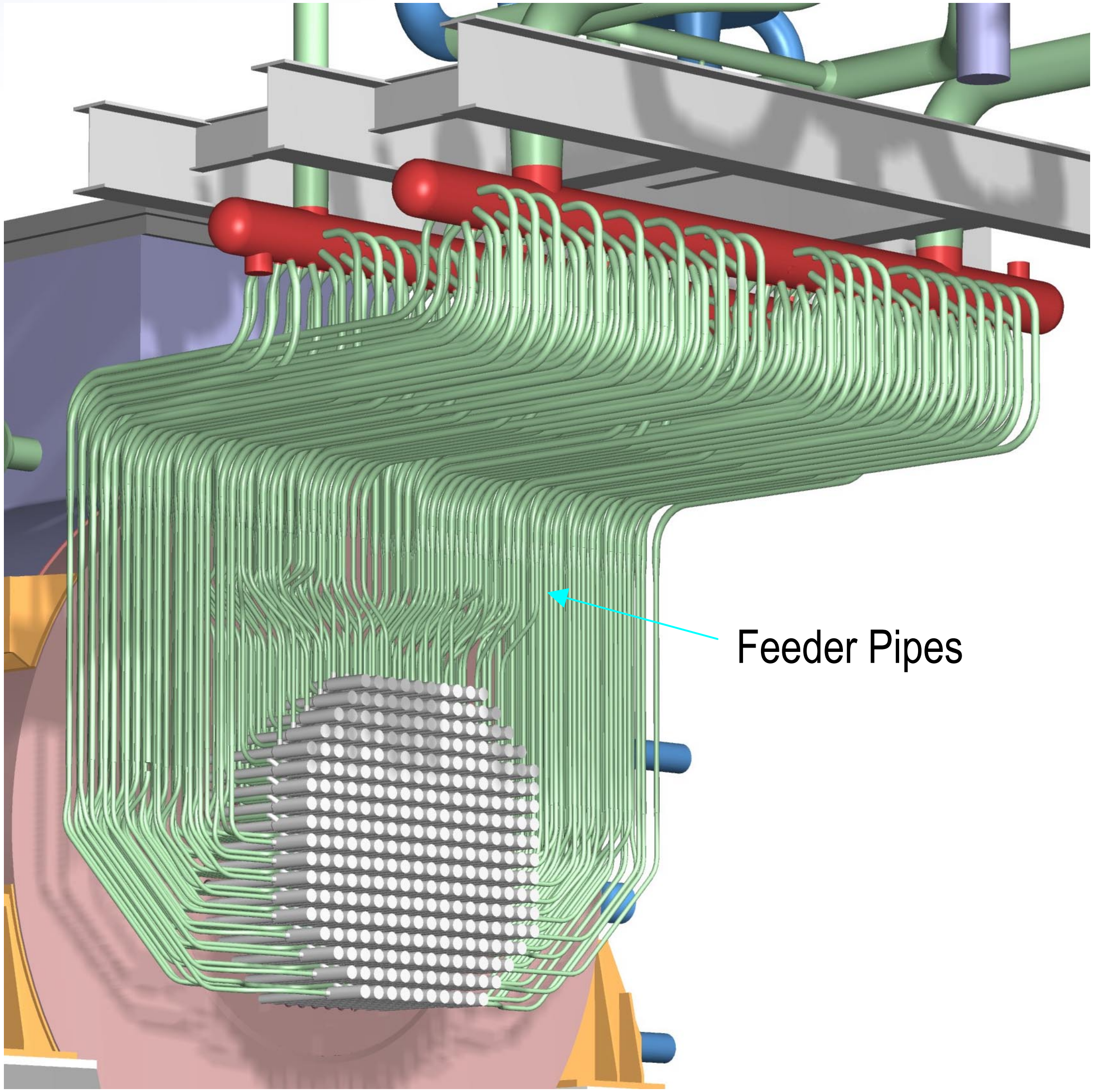
Outline

- Introduction
- Degrees of Flow Blockage
- Sequence of Events
- Results
- Summary

Introduction

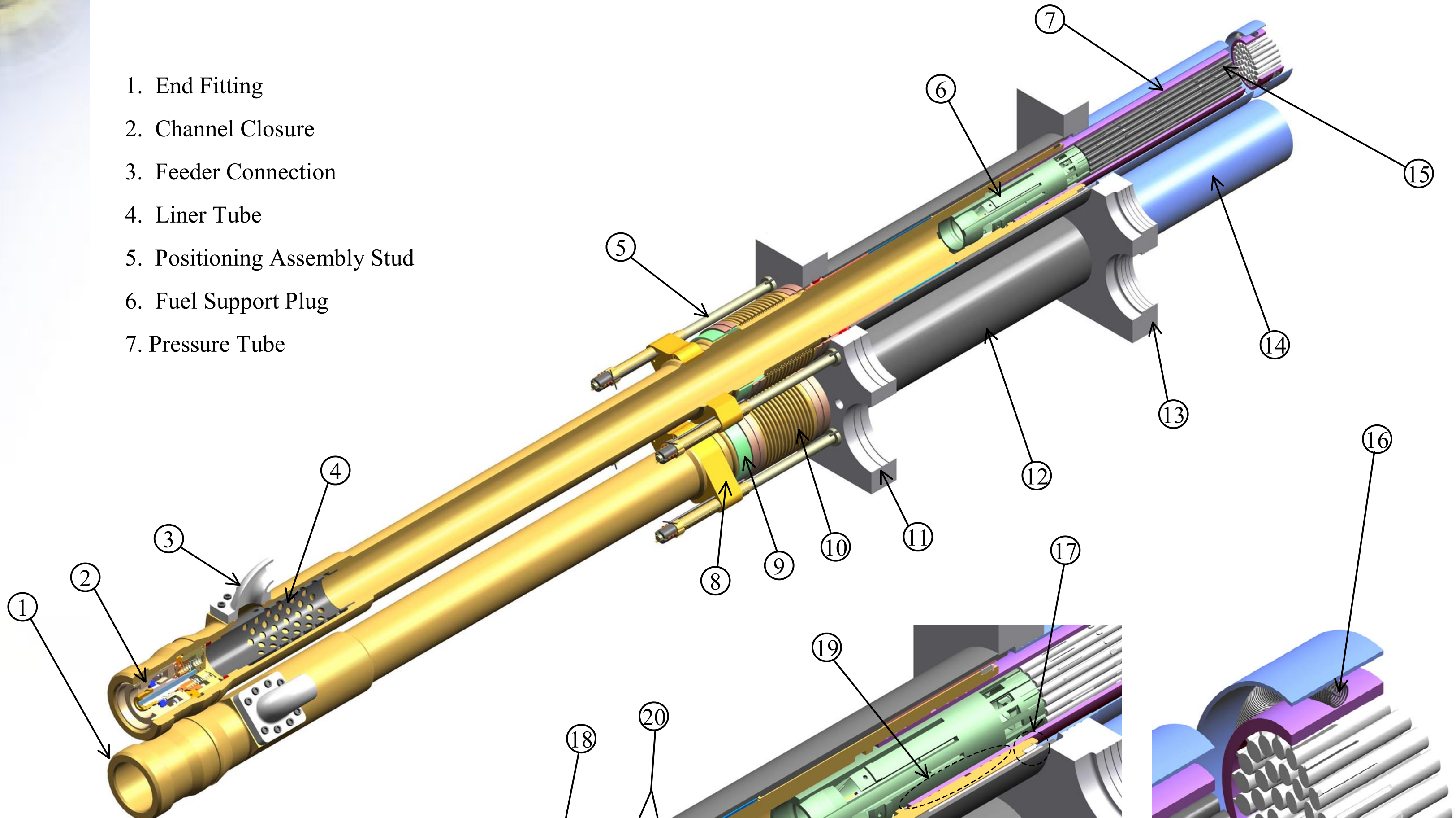
- **<u>Single Channel Event</u>: one of 292 channels affected.**
- **Feeder Stagnation – Channel Flow Blockage:**
  - **Initiating events differ;**
  - **Consequences of initiating event are the same:**
    - **Severe reduction in coolant flow (a range depending on break or blockage size),**
    - **Rapid fuel and channel heatup, and**
    - **Eventual failure of channel.**
  - **Evolution of accidents is essentially the same.**
- **After initiating event, discussion of accident progression is the same for both events.**

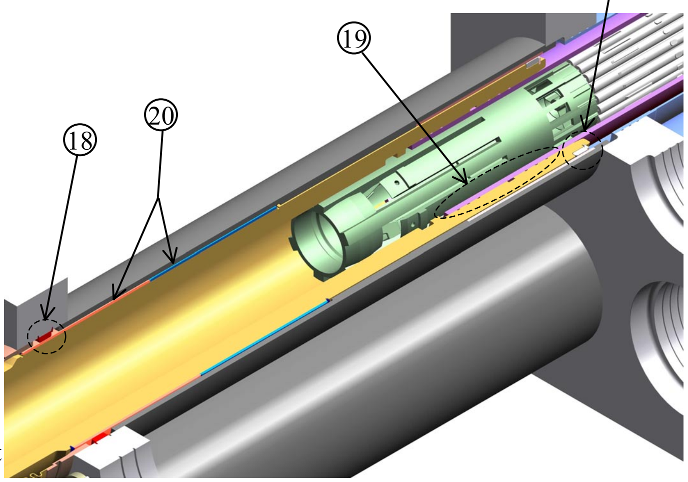
Reactor Cooling System

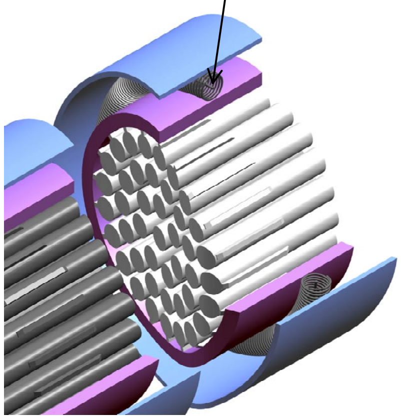


ACR Fuel Channel

1. End Fitting
2. Channel Closure
3. Feeder Connection
4. Liner Tube
5. Positioning Assembly Stud
6. Fuel Support Plug
7. Pressure Tube

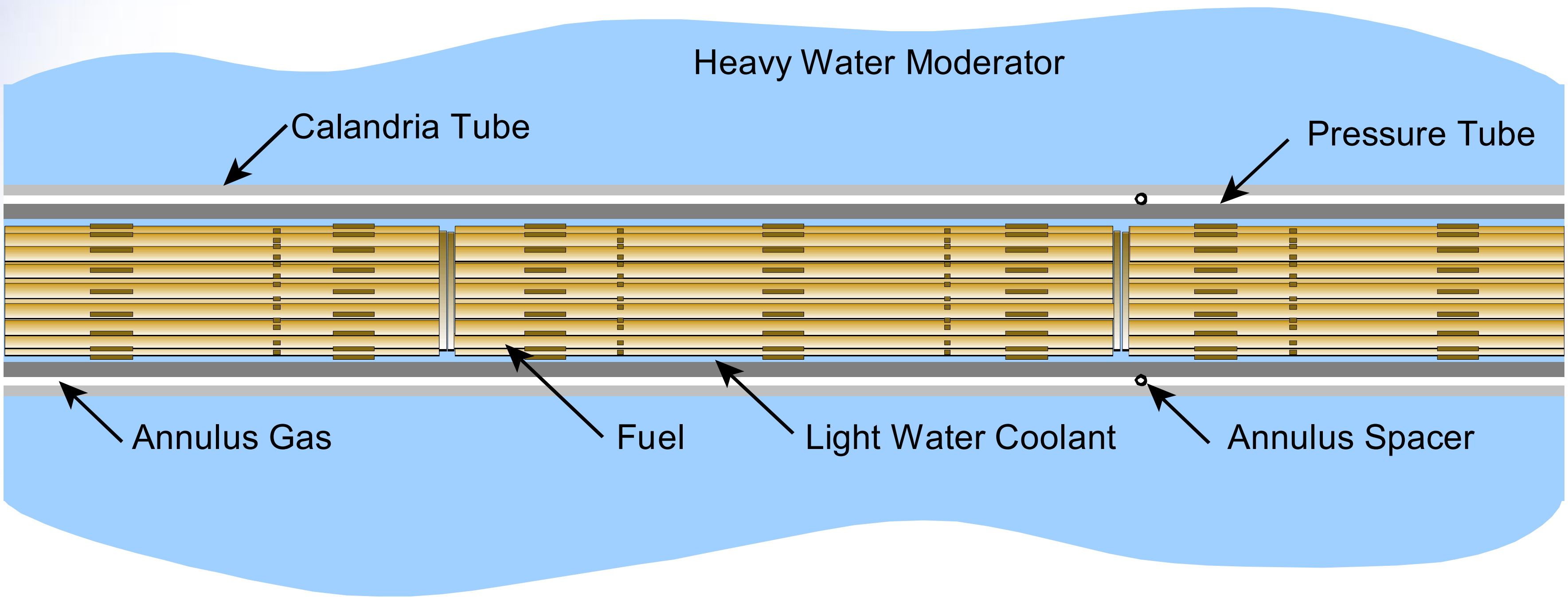






8. Position Assembly Yoke
9. Bellows Attachment Ring
10. Bellows Assembly
11. Fuelling Tubesheet
12. Lattice Tube
13. Calandria Tubesheet
14. Calandria Tube
15. Fuel Bundle
16. Channel Annulus Spacer
17. Inboard Journal Bearing
18. Outboard Journal Bearing
19. Pressure Tube Rolled Joint
20. Shielding Sleeves

ACR Fuel Channel



Degree of Flow Blockage

1. **Blockages that have little effect on fuel cooling.**
   - **The flow in the channel is reduced:**
     - **Fuel and fuel clad temperatures do not increase significantly;**
     - **These blockages do not present any immediate safety concerns since the fuel bundles, and the pressure tube, remain well cooled.**

Degree of Flow Blockage

2. **Blockages that result in transition boiling on some fuel cladding.**
   - **Flow in the channel decreases:**
     - **Film boiling begins on the clad of the hottest (highest power) fuel bundles;**
     - **Clad failures due to oxygen embrittlement may result (the time frame for the fuel failures under these conditions is on the order of several hours);**
     - **The RCS is intact, there are no releases into containment;**
     - **The flow blockage would be detected by the gaseous fission product monitoring system, the failed fuel detection system, or during the refuelling process.**

Degree of Flow Blockage

3. **Blockages that result in fully developed film boiling on the fuel clad.**
   - **Fuel clad failures due to oxygen embrittlement (the time frame for clad failures under these conditions is on the order of approximately half an hour);**
     - **The RCS is intact, there are no releases into containment;**
     - **The flow blockage would be detected by the gaseous fission product monitoring system, the failed fuel detection system, or during the refueling process.**

Degree of Flow Blockage

4. **Blockages that result in superheated steam being formed in the channel.**
   - **There is rapid stratification and boil-off of the coolant:**
     - **Leads to the generation of significant circumferential temperature gradients on the pressure tube while the reactor remains at full power and at full system pressure;**
     - **Fuel and clad temperatures rapidly increase to the point where molten clad may be generated inside the channel;**
     - **The combination of a substantial pressure tube temperature gradient with high system pressure, leads to pressure tube failure;**

Degree of Flow Blockage

4. There are two possible outcomes at this point:
   - (1) The pressure tube fails before clad melting temperature is reached;
     - After the pressure tube fails, the calandria tube bellows will fail, while the calandria tube remains intact, thereby establishing a coolant flow path from the blocked channel into containment;
     - The coolant flow will provide enough cooling to the fuel to prevent any clad melting.

Degree of Flow Blockage

- (2)Molten clad is generated prior to pressure tube failure;
  - After the pressure tube fails, the calandria tube will not be able to remain intact after molten clad is ejected from the pressure tube;
  - This results in the pressurization of the calandria vessel that is dependent upon the system conditions (pressure, temperature, amount of molten clad) prior to channel failure;
  - Some damage to in-core components may be sustained as a result of the pressure transient after channel rupture.

Flow Blockage/Break Area Survey

	No Fuel Failures	Fuel Failure, No Pressure Tube Failure	Pressure Tube Failure	Melt Generation
Blockage Area Reduction	0 - 78%	79% - 94%	94% - 98%	98% - 100%
Feeder Break Area	0% - 16% 100% - 37%	16% - 21% 37% - 30%	21%-23% 30% - 27%	23%-27%

Sequence of Events for Severe Blockage

1) The RCS remains unaffected, except in the blocked channel.

2) The fuel and pressure tube where the blockage occurs heat up rapidly as the coolant in the channel superheats:

   - A non-uniform temperature distribution develops on the circumference of the pressure tube.

   - Since the channel pressure is high, pressure tube circumferential strain begins as the pressure tube heats up.

3) As the coolant pressure is high, a small non-uniform circumferential temperature distribution is sufficient to result in pressure tube failure.

Sequence of Events for Severe Blockage

4) After pressure tube failure:

- The gas annulus between the pressure tube and calandria tube pressurizes very rapidly, and the calandria tube bellows rupture;
- Heat is transferred from the superheated steam discharging into the gas annulus to the calandria tube and from the calandria tube to the moderator;
- The calandria tube subsequently heats up, the combination of high pressure and thermal loads cause the calandria tube to rupture very soon after the pressure tube ruptures.

Sequence of Events for Severe Blockage

5) The possibility of molten clad generation prior to pressure tube failure cannot be ruled out entirely:

- If the pressure tube does not fail, the fuel clad would continue to heat up.
- Eventually, molten clad runs down onto the pressure tube.
- Even a thin layer of molten clad in contact with the pressure tube causes the pressure tube and calandria tube to heat up rapidly.
- The thermal transient is so rapid that failure temperatures are reached quickly.

Sequence of Events for Severe Blockage

6) After channel failure, the contents of the channel, consisting of superheated coolant, fission products and possibly overheated or molten clad, is rapidly discharged into the moderator:

- Fuel discharged into the moderator is quenched and cooled.
- What remains in the channel is effectively cooled by the reverse flow from the outlet header,and by coolant in the annulus between the pressure tube and the calandria tube.

Sequence of Events for Severe Blockage

7) The discharge of light water coolant into the heavy water moderator produces additional negative reactivity.

8) The rapid discharge of hot fuel and coolant into the calandria causes the moderator pressure and temperature to increase:

   - The increasing pressure in the calandria pushes the moderator up into the four relief ducts at the top of the calandria.
   - The pressure continues to rise until the rupture discs break open.
   - Once the rupture discs on the calandria relief ducts burst, the moderator level will increase to the high moderator level reactor trip setpoint, and the reactor will be shutdown.

Sequence of Events for Severe Blockage

9) Containment pressure and temperature rise:

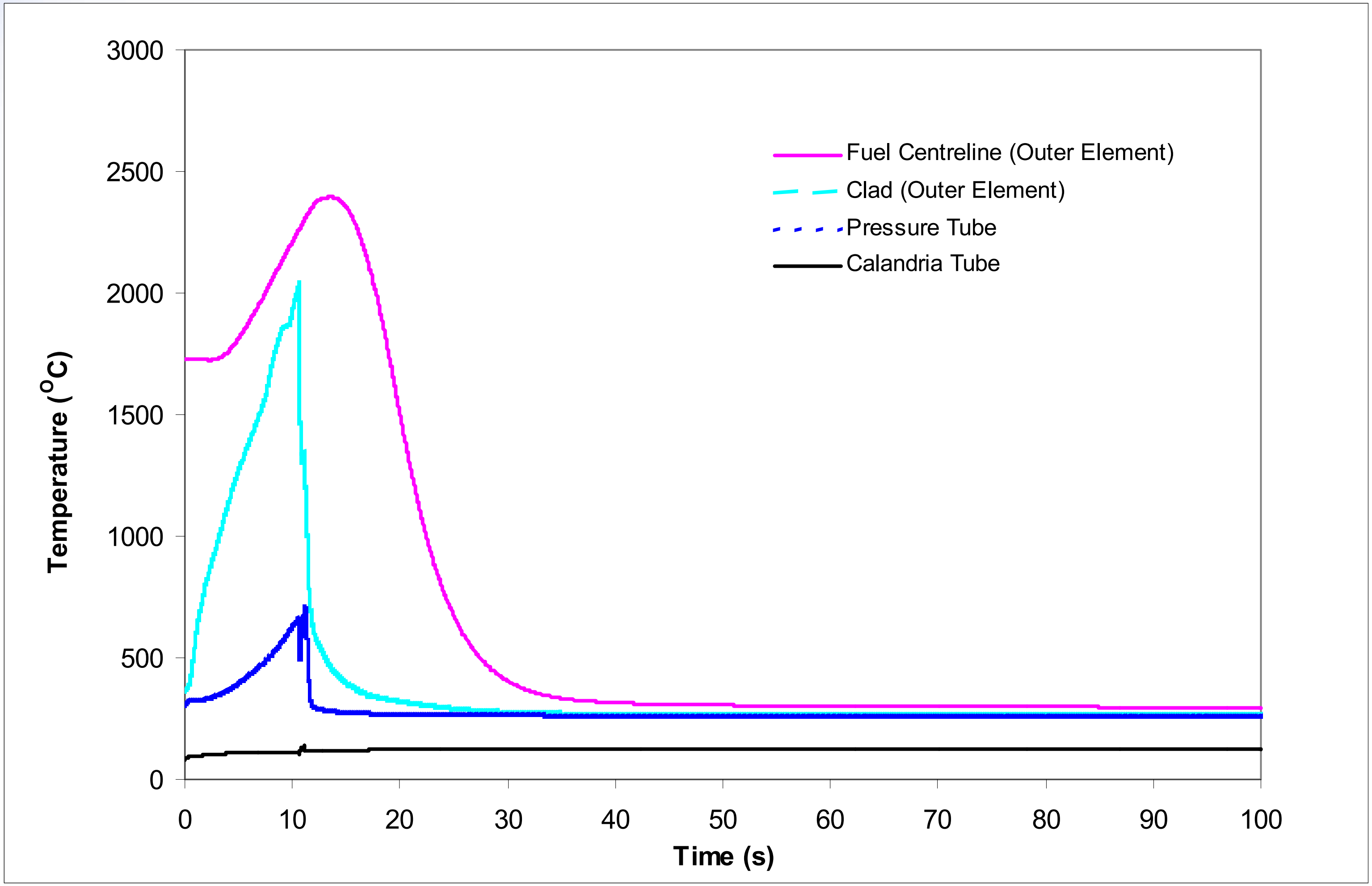
- Air coolers and condensation on the containment walls cool the containment atmosphere.
- Containment isolation is automatically initiated on the high containment pressure signal, if the pressure rise is high enough, or on the high radiation level signal.

Sequence of Events for Severe Blockage

10) The RCS behaviour after the reactor trip is similar to that for an in-core LOCA or a small out-of-core break:

- The RCS pressure falls below the emergency core cooling initiation setpoint.
- The ECC system is designed to prevent clad failures for small breaks in the RCS.
- Thus, clad temperatures in the intact channels remain near the coolant temperature and no fuel failures occur in the unaffected channels.
- The only significant radionuclide release from fuel occurs in the ruptured channel.

Results for Severe Flow Blockage



Summary

- There is a very narrow range of flow blockages and feeder breaks that will produce molten clad.
- The pressure tube will fail either by non-uniform strain or by contact with molten clad.
- To demonstrate the robustness of the design, unaffected channel integrity and calandria vessel integrity are demonstrated.

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