NTEC Module: Water Reactor Performance and Safety

Lecture 8: Loss-of-coolant accident (LOCA) phenomena

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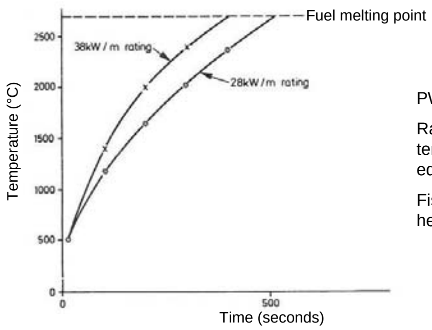
Reactor Operational States

- NORMAL OPERATION: Operation at full power.
- OPERATIONAL TRANSIENTS: Startup and shutdown. On-line refuelling (AGR).
- UPSET CONDITIONS: Unexpected faults, e.g. turbine trips. Loss of offsite power.
- EMERGENCY CONDITIONS: Break in small pipe, relief valve stuck open etc.
- LIMITING FAULT CONDITIONS (DESIGN BASIS ACCIDENTS): Design to cope with by engineered safety systems, e.g. large pipe break.

Frequency of occurrence of reactor operational states

Operating states for which the system is designed to cope:	
Normal operation	Continuous (apart from shutdowns for maintenance)
Operational transients	~ 10 per reactor year
Upsets	~ 1 per reactor year
Emergencies	1 in 100 reactor years
Limiting fault conditions (including design basis accident, DBA)	1 in 10,000 reactor years
Unprotected or beyond design basis accidents	1 in 1 million reactor years

Adiabatic heating of full elements after reactor trip



PWR fuel elements.

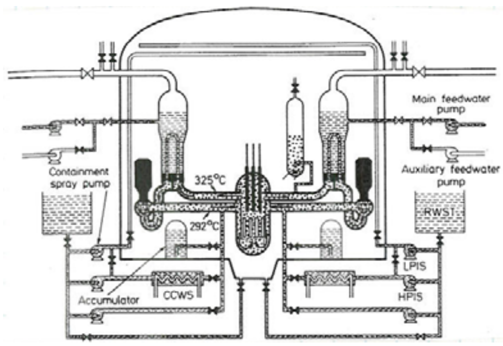
Rapid initial rise and temperature equalises.

Fission product heating continues.

Events in fuel element behaviour as temperature increases

Temperature (°C)	Phenomenon
350	Approximate cladding temperature during power operation.
800 – 150	Cladding is perforated or swells as a result of rod internal gas pressure in the post-accident environment; some fission gases are released; solid reactions between stainless steels and Zircaloy begin; clad swelling may block some flow channels.
1450 – 1500	Zircaloy steam reaction may produce energy in excess of decay heat; gas absorption embrittles Zircaloy, hydrogen formed. Steel alloy melts.
1550 – 1650	Zircaloy-steam reaction may be autocatalytic unless Zircaloy is quenched by immersion.
1900	Zircaloy melts, fission product release from UO_2 becomes increasingly significant above 2150 K.
2700	UO_2 and ZrO_2 melt.

Emergency Core Cooling System (ECCS) for PWR reactor



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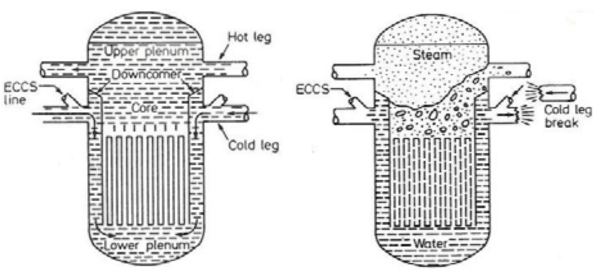
Events in a LARGE BREAK LOCA in a PWR (I)



Normal operation **Blowdown**

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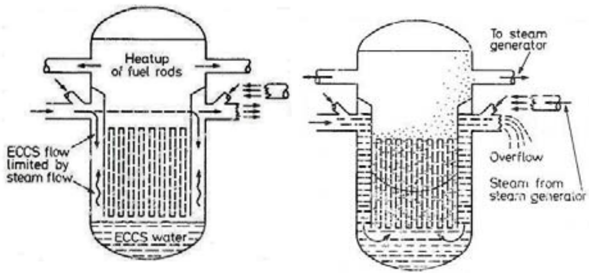
Events in a LARGE BREAK LOCA in a PWR (II)



Refill **Reflood**

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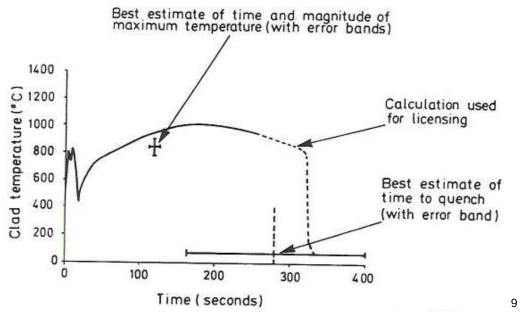
Variation of peak clad temperature with time in Large Break PWR LOCA



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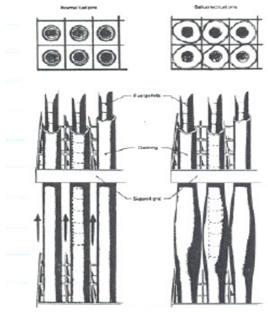
A complicating feature: Clad ballooning



Fuel elements in PWR are pressurise.

At temperatures above ca. 800 C clad swells and may block flow.

Further discussion in Lecture 10.

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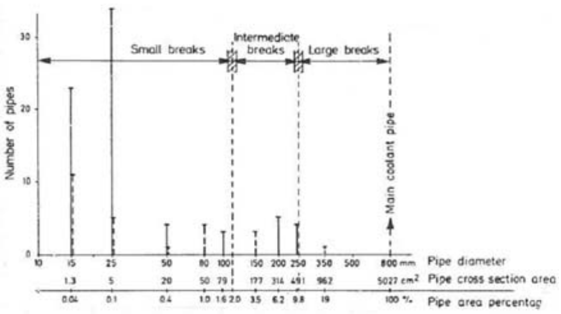
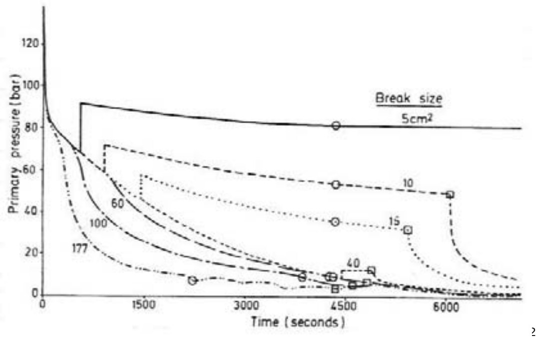
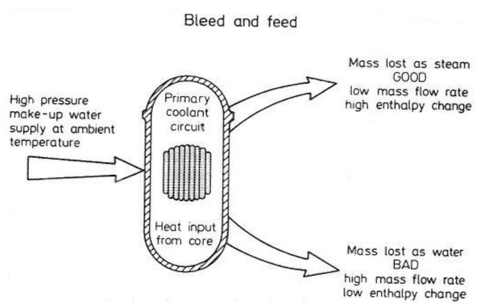
Small break LOCAs: Pipe Sizes



Small break LOCAs: Variation of pressure with time



Small break LOCAs: Energy outflows



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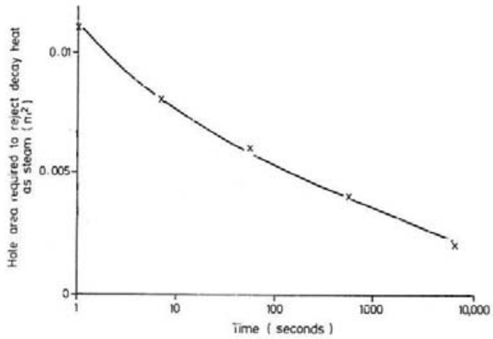
Small break LOCAs: Hole size to remove energy as steam



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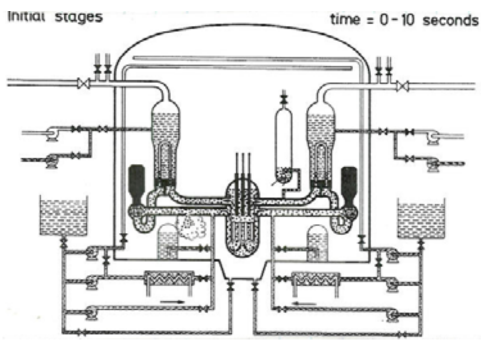
Small break LOCAs: Initial phase



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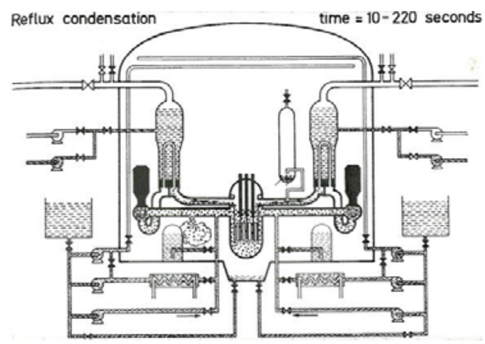
Small break LOCAs: Reflux condensation



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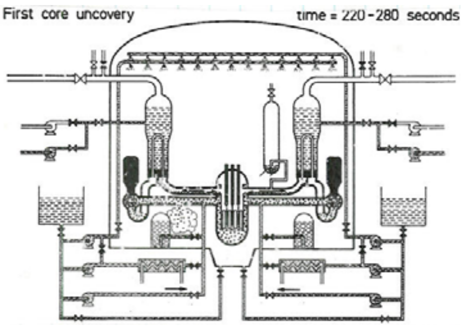
Small break LOCAs: Core uncovery



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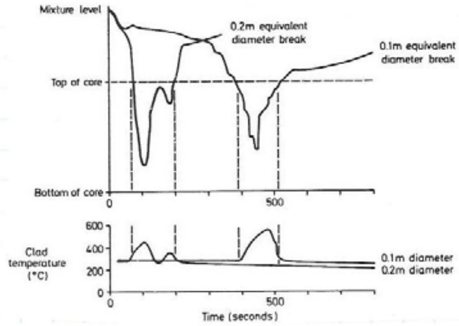
Small break LOCAs: Mixture level and clad temperature



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Conclusion

- Design over full range of operational states is vital.
- What seems to be the extreme case is sometimes not the most important (e.g. small break rather than large break LOCA's are worst case!)
- It is important to analyse and learn as much as possible from actual accidents.

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