Advanced CANDU Reactor

Safety Basis and Limited Core Damage Accidents

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Background

- ACR Safety Basis has been developed for a new design
- ACR Safety Basis is comprised of a sensible combination of Canadian and international requirements (particularly NRC requirements)
- ACR Safety Basis has adopted a risk-informed approach
- The need for more use of risk-informed safety analysis has been acknowledged in Canada and internationally
- The ACR risk-informed approach has been proposed to CNSC

Background

- AECL is undertaking two licensing efforts for ACR:
  - with CNSC to obtain a statement of licensability of the design, and
  - with NRC for a pre-licensing review leading to the application for standard design certification.
- The ACR Safety Basis approach was presented to CNSC and NRC in March 2003.
- Formal submission of the ACR Safety Basis to CNSC in July 2003. The document was also sent to NRC in July 2003.
- CNSC is developing the licensing basis for ACR. Discussions are taking place between AECL and CNSC.

General Approach

- Key to the safety basis approach is the definition and classification of events in and beyond the design basis of the plant
- ACR approach is founded on the risk-informed objective:
  - The most probable occurrences should yield the least radiological consequences, and situations having the potential for the greatest consequences should be least likely to occur

General Approach

- **ACR approach:**
  - adopts five classes of events with associated radiological dose limits
  - adopts acceptance criteria and targets that are based on safety margins increasing with the likelihood of the events in a class
  - uses assumptions and methods that provide a good balance between the need for conservatism at the higher event likelihood end of the classification and the reasonableness of a design centered assessment at the lower likelihood end.

General Approach

- Initiating events are identified through a systematic review of the plant design. The systematic review document was sent to the NRC in February 2004.
- The approach is consistent with international standards

Event Classification

- Three categories of events for ACR
  - Design basis events
  - Limited core damage accidents
  - Severe core damage accidents

Radiological Dose Limits

Limit	Event Class				
	1	2	3	4	5
Effective dose (Rem)	0.05	0.5	3	10	25

Design Basis Events

- Design basis events are events which must be accommodated by the plant design within specified limits of the radiological dose to the public and of the effects on the barriers against the release of radioactivity to the environment:
  - Fuel
  - Reactor Coolant Pressure Boundary
  - Containment
- The plant response to design basis events is analyzed using conservative assumptions and detailed models
- Safety analysis for Design Basis Events assumes single failure in the aggregate of mitigating systems

Design Basis Events

- **Three event classes in the design basis event category**
  - 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
- **Classification is consistent with that in NRC RG 1.70 Rev. 3**

Limited Core Damage Accidents

- Limited core damage accidents (LCDAs) are improbable events beyond the design basis which must be accommodated within specified radiological dose limits to the public
- LCDAs comprise Class 4 and 5 events
- LCDAs include combinations of events due to initiating events coincident with total failure of a safety system, and accidents with significant damage of the fuel localized in a single channel
- Targets on the performance of the barriers against the release of radioactivity may be set to facilitate meeting the dose limits
- Limited core damage accidents are analysed using design centered assumptions and detailed models

Limited Core Damage Accidents

- Two types of LCDAs strictly connected to the reactor design consisting of separate fuel channels surrounded by the low pressure moderator:
  - Accidents initiated in a single fuel channel with significant overheating of fuel material in the channel.
    - Severe flow blockage and feeder stagnation break
    - Heatup at high power and high pressure
    - Affected fuel channel fails before fuel melting
    - No propagation of the damage to neighboring channels, hence damage remains localized to the affected channel
  - Accidents with widespread overheating of the fuel in the core but not compromising core coolability
    - LOCA with loss of emergency core cooling
    - Heatup at decay power and low pressure
    - No channel failure and no fuel melting due to the heat transfer from the fuel to the cool moderator surrounding the fuel channels

Severe Core Damage Accidents

- Severe core damage (SCD) accidents are extremely improbable events beyond the design basis, which lead to loss of core geometry.
- Target is to have very low cumulative frequencies of severe core damage and large release from the containment.
  - Summed frequency of SCD events $<10^{-5}$ per year and summed frequency for accident sequences leading to large releases of radioactivity $< 10^{-6}$ per year
  - Summed frequencies include also external events except seismic (a seismic margin assessment is performed for earthquakes)
- Severe core damage accidents are analyzed using design centered assumptions and integral models
- Analyses are done as part of the PRA
- Example of major severe core damage accident is
  - LOCA + LOECC + unavailability of moderator heat sink

Overall Approach to Event Analysis

Event Category	Analysis Assumptions	Analysis Models	Acceptance Criteria/Targets
Design Basis Events (Classes 1,2 and 3)	*Conservative*	*Detailed*	*Performance Criteria/Targets and Radiological Dose Limits*
Limited Core Damage Accidents (Classes 4 and 5)	*Design Centered*	*Detailed*	*Performance Criteria/Targets and Radiological Dose Limits*
Severe Core Damage Accidents	*Design Centered*	*Integral*	*Targets for Frequencies of Severe Core Damage and Large Release*

Summary of Event Classification

Event Category	Event Class	Typical Frequency Range (Events per year)	Effective Dose Limit (Rem)	Event Examples
DBE	Class 1	$> 10^{-2}$	0.05	•Loss of offsite power •Loss of normal feedwater
DBE	Class 2	$10^{-2} – 10^{-3}$	0.5	•Small LOCA •Partial single channel flow blockage •Off-stagnation feeder break
DBE	Class 3	$10^{-3} – 10^{-4}$	3	•Large LOCA •Large Steam line Break
LCDA	Class 4	$10^{-4} –10^{-5}$	10	•Stagnation Feeder Break (Class 4 or 5, under evaluation)
LCDA	Class 5	$10^{-5} – 10^{-6}$	25	•Large LOCA + LOECC •Severe Flow Blockage
SCD	_	$< 10^{-6}$	_	•Large LOCA + LOECC + loss of moderator heat sink

Characteristics of Major Events

Event	Event Category	Event Class	Major Acceptance Criteria	Consequences
Feeder failure – Off-stagnation feeder break	DBE	2	No fuel failures in unaffected channels. Radiological dose limit.	Fuel overheat (but no melting) in the affected channel. No channel failure.
Partial single channel blockage	DBE	2	No fuel failures in unaffected channels. Radiological dose limit.	Fuel overheat (but no melting) in the affected channel. No channel failure.
Reactor coolant system large LOCA	DBE	3	Limited fuel failures. No channel failure. Containment pressure limit. Radiological dose limit.	Fuel overheat and possible fuel failures. Containment pressurization.
Feeder failure – Stagnation feeder break	LCDA	4 or 5	No fuel failures in unaffected channels. No channel failure propagation. Radiological dose limit.	Significant overheating of fuel in the affected channel leading to PT failure but no fuel melting. Moderator pressurization.
Severe channel flow blockage	LCDA	5	No fuel failures in unaffected channels. No channel failure propagation. Radiological dose limit.	Significant overheating of fuel in the affected channel leading to PT failure but no fuel melting. Moderator pressurization.
Reactor main coolant system large LOCA + failure of emergency coolant injection.	LCDA	5	Coolable core geometry. Containment pressure limit. Radiological dose limit.	Fuel overheat (but no fuel melting) and PT deformation, limited by heat transfer to moderator.

Conclusion

- The safety basis was presented to CNSC and NRC, and has been formally submitted to CNSC
- ACR safety basis uses risk-informed approach
- It features a rigorous approach to safety analysis; in particular:
  - Very conservative analyses for design basis events
  - Detailed models for the analysis of both design basis events and limited core damage accidents

Conclusion

- LCDAs comprise events with significant fuel damage localized in one channel as well as events leading to widespread core overheating but with no fuel melting
- LCDAs are intimately connected to the reactor design consisting of separate fuel channels surrounded by low-pressure, cool moderator which can act as a heat sink for decay heat after shutdown
- Safety for LCDAs is ensured by keeping the dose to the public within limits which are consistent with international standards
- ACR safety basis also includes the treatment of severe core damage accidents in PRA
- The structure of event categories/classes and respective acceptance criteria and targets is fully consistent with international practice

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