CANDU Safety
#21 - Regulation of CANDU

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Director
Safety & Licensing
1. **Why Regulate At All?**

- Nuclear power is complex and potentially dangerous.
- Minimum public safety requirements should be the same everywhere in the host country (Canada), so there is a need for regulation at the national government level.
- Countries which purchase CANDU should ensure the product meets national requirements (as appropriate to the design).
- Independent review is a powerful means of avoiding complacency and group-think.
2. **Legal Basis for the Canadian System**

- After the war, Canada’s heavy-water reactor programme was reoriented to civilian nuclear power.
- Atomic Energy Control Act (1946)
  - declared atomic energy as matter of national interest
  - established Atomic Energy Control Board (AECB) to administer it
- 1960 - extended to health & safety
- Emphasis has moved from control of information to public safety
- Regulation process & results in Canada are open to the public.

*ZEEP - The First Reactor to Go Critical Outside The USA, in September 1945*
Structure of the Canadian Nuclear Industry

FEDERAL GOVERNMENT

MINISTER

NATURAL RESOURCES CANADA

AECB

Advanced CANDU

AECL

Licensing

ELECTRIC UTILITY

Design &c

PROVINCIAL GOVERNMENT
Atomic Energy Control Board
Five Member Board, about 400 staff

- President of the AECB (Board) is also head of the AECB (Staff)
- regulation of all civilian nuclear radiation activities
- operating licences for all nuclear facilities in Canada
- resident staff at all Canadian nuclear stations
- administers international nuclear & proliferation policy
- regulatory training to nations interested in CANDU
- reviews Environmental Assessment on behalf of gov’t
Regulations Structure (Today)

Atomic Energy Control Act

Regulations

Regulatory Documents (R-series)

Consultative Documents (C-series)

Precedent, Practice & Innovation
Regulations Structure (Today)

- **Regulations** - enforceable by law
- **R-series** - regulatory documents - hard requirements, not law
- **C-series** - consultative, developing or draft regulatory documents
- R- & C- documents cover safety analysis, requirements for safety-related systems, quality assurance, operations, decommissioning, etc.
- *non-prescriptive and results-oriented*: encourages innovation & avoids inherent conflict of interest
Four Simple Steps to Licensing a Nuclear Power Plant

1. Letter of Intent
2. Site Acceptance
   - site evaluation and proposed design
   - environmental assessment
   - public consultation
3. Construction Licence
   - Preliminary Design and Preliminary Safety Report
4. Operating Licence
   - Final Design and Final Safety Analysis Report
Regulations Structure (Coming Soon)

Nuclear Safety & Control Act

- Regulations
- Regulatory Policy
- Regulatory Standard
- Regulatory Guide
- Regulatory Notice
- Regulatory Procedure

Regulatory Guidance Documents: Compliance optional unless incorporated in licence
### New Regulatory Documents

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory Policy</td>
<td>Philosophy, guides AECB Staff and applicants</td>
</tr>
<tr>
<td>Regulatory Standard</td>
<td>Measurable evaluation criteria, can be put in licence</td>
</tr>
<tr>
<td>Regulatory Guide</td>
<td>AECB accepts and recommends but not put in licence</td>
</tr>
<tr>
<td>Regulatory Notice</td>
<td>Advice &amp; information</td>
</tr>
<tr>
<td>Regulatory Procedure</td>
<td>AECB Work Processes</td>
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</table>
3. **Regulatory Philosophy in Canada**

- **origins**
  - small country, single unique reactor type, single designer
  - government sponsored & developed
  - “on our own”
- **safety responsibility on owner, regulator audits**

**Prescriptive**

Regulator tells you what to do and how to do it

**Non-Prescriptive**

Regulator tells you what safety requirements you have to meet and you find the best way of doing it
4. **Major Regulatory Requirements in Canada**

- initial safety goal (1960s): risk of prompt death in nuclear accident < 1/5 risk of death in coal, or 0.2 deaths/year
- led to probabilistic treatment on Douglas Point
  
  Total risk =

  \[ \sum (\text{probability of accident}) \times (\text{consequence of accident}) \]

  < safety goal

- requires:
  - design to ensure low *frequency* of accidents
  - design, test & maintain to *demonstrate availability*
  - *separate* normal and safety systems
Evolved to More Deterministic Requirements:
The Single/Dual Failure Approach

- Single Failure - failure of a system used in the operation of the plant (e.g., LOR, LOCA)
- Dual Failure - single failure combined with the assumed unavailability of a safety system
- dose and frequency/unavailability limits assigned
- one shutdown system must be assumed unavailable in all accident analysis
- reactors before Darlington all licensed using this approach
Safety System Requirements

- SDS1, SDS2, containment, ECC
- must be:
  - independent
  - testable to unavailability of $10^{-3}$ years/year
  - diverse & redundant (shutdown systems)
  - fail safe to extent practical
  - separate from process systems and each other - minimum shared components
## AECB Single-Dual Failure Criteria

*(from R-10)*

<table>
<thead>
<tr>
<th></th>
<th>SINGLE FAILURES</th>
<th>DUAL FAILURES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WHOLE BODY</td>
<td>THYROID</td>
</tr>
<tr>
<td>INDIVIDUAL</td>
<td>0.005 Sv</td>
<td>0.03 Sv</td>
</tr>
<tr>
<td>POPULATION</td>
<td>100 per-Sv</td>
<td>100 per-Sv</td>
</tr>
</tbody>
</table>
AECB SINGLE-DUAL FAILURE CRITERIA
(Up to Darlington)

Single failure

Dual failure

Frequency (/ry)

Whole body dose (Sv)
**Single/Dual Failure - Why So Special?**

- maximum process failure frequency large enough (1 in 3 years) that it can be *shown* to be met
- requires *demonstration* of claimed reliability for special safety systems
- requires consideration of severe accidents (LOCA+LOECC) *within* design basis
  - hydrogen in the Three Mile Island accident was a surprise to the LWR community but had been analyzed in Canada for years
**Single/Dual Failure - What’s Missing**

- treats rare accidents (large LOCA - $10^{-5}$ per year) and less rare accidents (loss of reactivity control - $10^{-1}$ per year) on same basis
- does not have a good framework for safety related systems other than special safety systems
  - instrument air, electrical power, process water
- can miss multiple failures which have frequency comparable to the single or dual failures
- led to Probabilistic Safety Analysis and AECB Document C-6
Probabilistic Analysis

- explicitly account for probability of an accident in calculation of risk
- incorporate probability of plant state
- model mitigating system reliability and performance realistically
- compare to acceptance criteria set by designer
AECB Introduces C-6

- first used on Darlington
- 5 event classes but not explicitly assigned to frequency
- requires *systematic plant evaluation* to capture all events
- a poor man’s Probabilistic Safety Analysis with deterministic rules
AECB Consultative Document C-6 Criteria
(Darlington’ & after)

* as applied

Whole body dose (Sv)

Implied Frequency (/ry)

Class 1

Class 2

Class 3

Class 4

Class 5
**Other Major Regulatory Documents**

- R-7 Containment
- R-8 Shutdown Systems
- R-9 Emergency Core Cooling System
- R-10 Use of Two Shutdown Systems
- C-22 Quality Assurance
- R-77 Overpressure Protection Requirements
- R-90 Decommissioning
- C-98 Reliability
- R-99 Reporting
- C-129 ALARA
5. **Prescriptive Regulation - The U.S. Approach**

<table>
<thead>
<tr>
<th>U.S.</th>
<th>Canada</th>
</tr>
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<tbody>
<tr>
<td>Many vendors, many designs</td>
<td>One vendor, one design</td>
</tr>
<tr>
<td>Legal-oriented</td>
<td>Consensus oriented</td>
</tr>
<tr>
<td>About 6 binders of detailed laws (Code of Federal Regulations)</td>
<td>About 100 pages of laws</td>
</tr>
<tr>
<td>Prescribes overall requirements plus specific acceptance criteria and how to do design</td>
<td>Prescribes high-level acceptance criteria; onus on designer to justify the design</td>
</tr>
<tr>
<td>Easy to “check-off” that the rules have been met by a foreign regulator</td>
<td>Hard for others to understand process and needs deep understanding of CANDU to apply</td>
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Example: Sheath Embrittlement in Large LOCA

- U.S. 10CFR50 Section 46(b(1)
  - “The calculated maximum fuel element cladding temperature shall not exceed 2200°F”
- Canada - R-9, Section 3.2(c)
  - “All fuel in the reactor and all fuel channels shall be kept in a configuration such that continued removal by ECCS of the decay heat produced by the fuel can be maintained...”
- U.S. - prescribes not only limit but models used to calculate it
- Canada - describes objective and up to designer to do tests and develop models to prove it is met
6. **IAEA - Toward World Regulations**

- IAEA - International Atomic Energy Agency
- UN body, HQ in Vienna
- “to accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world”
- Hence:
  - safeguards
  - safety
  - promotion
IAEA Safety Documents

Safety Fundamentals
Basic Objectives, Concepts & Principles

Safety Standards
Basic Requirements for specific applications

Safety Guides
Recommendations
Examples and Methods

Safety Practices

CANDU complies directly or “meets intent”
Specific Changes to Wolsong 2,3&4 & Qinshan 1&2

- reorganized Safety Report per USNRC format
- meet Canadian and Korean or Chinese requirements for siting
- Level 2 PSA with external events, performed by Korea
- first application of AECB Consultative Document C-6 on a CANDU 6
- comprehensive dual parameter trip coverage
- Technical Support Centre
- Critical Safety Parameter Monitoring System

Wolsong 1, 2, 3, & 4
Specific Changes to Wolsong 2,3&4 & Qinshan 1&2 - cont’d

- tornado protection of key safety related systems on Qinshan due to site characteristics
- seismically qualified fire protection system in addition to existing two-group design approach

Qinshan Phase 3 - Units 1&2
(Projected appearance - site being prepared)
8. **Conclusions**

- Canadian goal-oriented licensing regime facilitates licensing in diverse jurisdictions although it may be harder to understand.
- CANDU owners develop their own licensing system incorporating the best of Canadian and national requirements.
- IAEA is slowly becoming an international regulator and its requirements are met.