Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Regulatory Design Evaluation of Advanced Reactors in Canada

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Consultancy on Safety of Sodium Cooled Fast Reactors

June 23-24, 2015, IAEA, Vienna, Austria

nuclearsafety.gc.ca

e-Docs # 4675974

Canada

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Vendor Design Review vs Design Process

PHASES OF REACTOR DESIGN

REACTOR DESIGN COMPLETENESS

Conceptual Design

VENDOR establishes design rules and processes

0%

Pre-licensing review of a vendor reactor design by the CNSC

Basic engineering program:
- safety design guides
- design requirements
- safety specification
- design quality assurance processes

Detailed design for a construction licence:
- preliminary safety analysis report
- design descriptions
- technical specifications of structures, systems and components to the level of detail for purchase orders
- detailed design quality assurance program
- all safety-related research and developments is complete

VENDOR AND LICENSEE collaborate on a facility safety case to demonstrate that the detailed reactor design is adequate.
The goal is a design that is sufficient for a construction licence application

Construction licence application to the CNSC

Detailed design for an operating licence:
- final safety analysis report
- design manuals
- commissioning manuals
- operating manuals

VENDOR AND LICENSEE finalize safety case to demonstrate that the reactor is built per design and will operate safely

Operation licence application to the CNSC

100%

Vendor provides ongoing design support to licensee

Canadian Vendor Design Assessment Process

- **Voluntary Pre-Licensing 3 step process:**
  - ***Phase 1:*** **Assessment of compliance with regulatory requirements to confirm that the design intent complies with CNSC design requirements (RD-337, RD-367 and from now on REGDOC 2.5.2*)*, and related regulatory requirements**
  - ***Phase 2:*** **Identification of potential fundamental barriers to licensing the reactor design in Canada**
    - **Secondary objectives of Phase 2 review:**
      - ✓ **Significant level of assurance that vendor has taken CNSC design requirements into account**
      - ✓ **Attention on new design features & approaches (to ensure that adequate testing & analysis were performed or are planned)**
      - ✓ **Attention on successful resolution of generic and outstanding safety issues**
  - ***Phase 3:*** **Pre-construction follow-up on one or more focus areas covered in Phase 1 and 2**
- **Construction License Application detailed review**

Canadian Vendor Design Assessment Process - Assessment Topics

#	Topic	
1	General NPP Description, Defense-in-Depth, Safety Goals, Dose Acceptance Criteria	
2	Classification of Structures, Systems & Components	
3	Nuclear Design of Reactor Core	
4	Fuel Design & Qualification	
5	Control Systems & Facilities	
6	Means of Reactor Shutdown	
7	Emergency Core Cooling & Emergency Heat Removal Systems	
8	Containment & Civil Structures Important to Safety	
9	BDBAs & Severe Accident Prevention & Mitigation	
10	Safety Analysis	

Canadian Vendor Design Assessment Process - Assessment Topics (cont.)

#	Topic	
11	Pressure Boundary	
12	Fire Protection	
13	Radiation Protection	
14	Out-of-Core Criticality	
15	Robustness & Seismic Issues	
16	Safeguards & Security	
17	Vendor R&D Programs	
18	Management System of Design Process & Quality Assurance in Design & Safety Analysis	
19	Human Factors	
20	Incorporation of Decommissioning Design Considerations	

Canadian Vendor Design Assessment Process

- Product of each of the vendor design assessment Phases (pre-licensing Phases 1, 2, 3 or Construction License Application) is a proprietary report with conclusions specific to each step provided to both vendor and utility

- Phase 2 of pre-licensing review provides an additional report from a mandatory audit of vendor's QA practices and is a key to identifying all potential barriers to licensing for a given plant design

- CNSC review process is similar to UK GDA, i.e. science based with the vendor to make the safety case (level of detail however vary)

- CNSC review scope (focus topics) are a hybrid of the US NRC and UK ONR approaches

Perspective on Canadian Vendor Design Assessment Process

- **CNSC perspective on design assessment process:**
  - **Design requirements differ between the countries - this affects the vendor design review process**
  - **Harmonization of the requirements is not straightforward but knowledge of differences is important to both designers and reviewers**
  - **Assessment of foreign or new technology depends strongly on flow of information between the vendor and the reviewer**

Canadian Vendor Design Assessment Process

- **CNSC perspective on design assessment process *(continued):***
  - **Ability to credit other jurisdiction reviews can facilitate the assessment but also depends on transfer of information**
  - **Harmonization of the scope of assessment could be beneficial to crediting other jurisdiction reviews**
  - **CNSC (as well as UK GDA) do not accept by default design certification**

Regulatory Design Requirements for New Reactors

- Design requirements in Canada are given in recently approved REGDOC 2.5.2 which replaces RD-337

- Current Canadian regulatory design requirements are technology neutral (i.e. generic in nature), however, they are based on light or heavy water technologies

- They incorporate lessons learned from domestic and international accidents:
  - NRX Research Reactor at Chalk River (1952) - Introduced concept of dual failure accident analysis and safety-support systems
  - Three Mile Island B&W PWR Accident (1979) and the Chernobyl RBMK Accident (1986) - Introduced safety goals, periodic safety analysis and defence in depth approach
  - Fukushima Daiichi 4 GE BWR Units (2011) - Introduced complementary design features and emergency management concepts and additional regulatory requirements

Regulatory Design Requirements for New Reactors

- **The goal of new regulatory requirements is to strengthen reactor defense in depth**

- **New regulatory requirements of REGDOC 2.5.2 are based on recommendations of the CNSC Fukushima Task Force Report (October 28, 2011) in the following areas :**

  - **Design Provisions**
  - **Hazards and analysis**
  - **Methodologies for external hazards**
  - **SAMG and severe accident models**
  - **Portable equipment**
  - **Strategies for protecting containment**
  - **Spent fuel pools**
  - **Demonstration of SAM effectiveness**

Regulatory Design Requirements for New Reactors

- **Key New Design Provisions in REGDOC 2.5.2:**
  - **Complementary Design Features and Passive Systems**
    - GREGDOC 2.5.2: greater emphasis on design of complementary design features and the use of passive systems. Detailed review of these features is in Topic 10 (Safety Analysis)
  - **Hydrogen Mitigation for the Spent Fuel Storage Pool**
    - REGDOC 2.5.2: additional requirements related to hydrogen mitigation in the spent fuel pool area
  - **Containment Venting**
    - REGDOC 2.5.2: design precludes unfiltered and uncontrolled releases from the containment. Containment performance is assessed in Topic 8 and BDBAs aspects of it are assessed in Topic 9 (BDBA & Severe Accidents)

Regulatory Design Requirements for New Reactors

- **Key New Design Provisions in REGDOC 2.5.2 continued:**

  - ***External Hazards***
    - **Generic assessment of external hazards is covered in Topic 10 (Safety Analysis) . Site specific hazards would be addressed with an application to construct**

  - ***Operator Intervention Times***
    - **REGDOC 2.5.2 incorporates changes and additional requirements related to credits for operator action. The design must be such that no control room action is needed for 30 minutes, no field action using installed equipment is for 1 hour, no need for onsite mobile equipment for 8 hours and no need for offsite support for 72 hours**

  - ***Spent Fuel Storage***
    - **REGDOC 2.5.2: more rigorous requirements for spent fuel storage pools. Detailed review of civil structures is in Topic 8 (Containment & Civil Structures)**

Strengthening Safety

- Regulatory, safety and design requirements are evolving together due to a feedback loop of operational and accidents experience
- The general tendency is for increasingly tight safety requirements
- These requirements are being applied not only to new designs but also to the current operating fleet, as well as fuel cycle facilities

Strengthening Safety

- In terms of design generations:
  - *Early prototypes:* basic systems intended for a limited scope of Design Basis Accidents (DBAs)
  - *Current PWR, BWR, HWR:* improved safety systems to mitigate a wider range of DBAs
  - *New designs (AP1000, EC6, EPR, ABWR, etc):* full set of safety systems for mitigating DBAs and severe accidents and greater reliance on passive and inherent safety features
  - *Future designs (so called "GEN IV"):* move towards greater reliance on inherent safety features

Challenge of new Reactor Designs to Regulatory Design Evaluation

- **There are three categories of reactor designs that may require regulatory evaluation in Canada:**

  - ***New designs (Gen III, III+):* CNSC recently completed evaluations of AP1000 (Pre-project Phases 1 and 2), EC-6 (Pre-project Phases 1, 2, and 3), ATMEA (Phase 1)**
  - ***SMRs:* a possible future entry**
  - ***Future designs (so called "GEN IV"):* so far hypothetical but CNSC is looking forward**

Challenge of New Reactor Designs to Regulatory Design Evaluation

- ***New designs (Gen III, III+):***

  - **Recently completed by CNSC pre-project vendor design evaluations (AP1000, EC6, ATMEA) constituted a benchmark test for the regulatory framework relevant to this category of designs. This test was successful and showed robustness of the CNSC regulatory design requirements**

- **SMRs:**

  - **A possibility for a SMR regulatory design evaluation in Canada is real and the probable design is mPower by B&W**

  - **The current regulatory framework is well suited for the regulatory design evaluation of this design which is a scaled down enhanced version of a PWR**

Challenge of New Reactor Designs to Regulatory Design Evaluation

- ***Future designs (so called "GEN IV"):***

  - **CNSC is following development of the GEN IV concepts from the point of view of the challenge that they may pose to regulatory design evaluation, in particular, from the point of view of regulatory design requirements of REGDOC 2.5.2**

  - **The GEN IV reactors introduce design concepts and safety approaches which may require additional requirements and guidance to be developed**

  - **Regulatory evaluation area where such challenge is particularly expected is that of Safety Analysis. This is because GEN IV concepts represent, in most cases, a departure from the water based technology**

Challenge of New Reactor Designs to Regulatory Design Evaluation

- **For GEN IV systems, there is a set of additional questions that have to be analyzed in detail, compared to the modern advanced water reactors, in particular, associated with:**

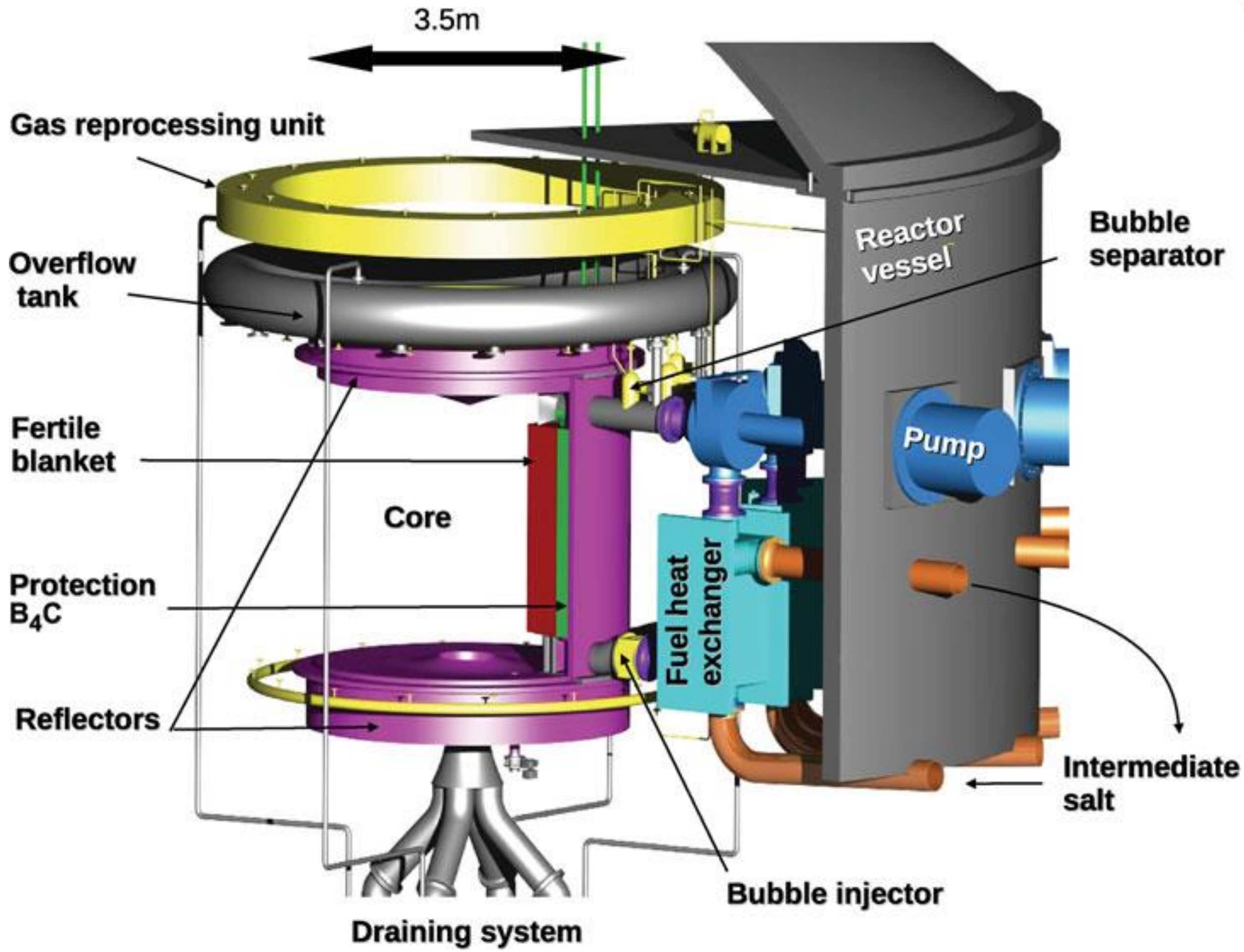
  - **Non-water coolants used in most of the GEN IV designs**
  - **Higher operational temperatures**
  - **Higher reactor power density**
  - **In some cases, close location or integration of fuel-cycle or chemical facilities, etc**
  - **The capability of GEN IV systems to achieve the safety goals (that would be established) must be demonstrated.**

Challenge of New Reactor Designs to Regulatory Design Evaluation

- **Any GEN IV nuclear system will only be licensed if it fulfills the stringent requirements summarized in the GEN IV Safety and Reliability goals:**
  - **Excel in safety and reliability**
  - **Have a very low likelihood and degree of reactor core damage**
  - **Eliminate the need for offsite emergency response**

- **Six concepts were selected by GEN IV International Forum (GIF):**
  - **Gas-Cooled Fast Reactor (GFR)**
  - **Lead-Cooled Fast Reactor (LFR)**
  - **Molten Salt Reactor (MSR)**
  - **Sodium-Cooled Fast Reactor (SFR)**
  - **Supercritical-Water Reactor (SCWR)**
  - **Very-High-Temperature Reactor (VHTR)**

Challenge Example: Gen IV Molten Salt Fast Reactor (MSFR) – A Homogeneous Reactor



Ref: *Nucl Sci Eng*, 175, **329-339** (2013)

Challenge Example: Gen IV Molten Salt Fast Reactor (MSFR) – A Homogeneous Reactor

- **Safety concerns:**
  - **Pumps should be provided with an inertia system for safety reasons (circulation of the salt coupled with reactivity)**
    - ✓ **failure of a single pump is potentially a severe accident**
    - ✓ **in current reactors, a single pump failure is not a concern**
  - **After shutdown, potential for breach of plant components due to decay heat**
  - **Fuel salt properties change because of fission products – online reprocessing needed**
  - **Variation in extracted power = a transient (temperature effects)**
  - **Fast negative reactivity feedbacks affect safety analysis**
  - **Fuel salt storage in the storage system must ensure sub-criticality and passive cooling**
  - **Analysis challenge: strong neutronics and thermalhydraulics coupling**
  - **Need to identify main accidents that can occur to define DBAs**

Conclusions

- Canadian vendor design review process is well established and tested during pre-project vendor design evaluations of new designs (AP1000, EC6, ATMEA)

- Regulatory design requirements for new designs given in REGDOC 2.5.2 are technology neutral, reflect lessons learned from all major domestic and international nuclear accidents and represent the state-of-the-art in nuclear safety

- Future GEN IV designs departing from water-based technologies may require additional regulatory requirements and generally constitute a challenge from the point of view of Safety Analysis

- CNSC is actively involved internationally to identify early all regulatory challenges associated with future GEN IV designs