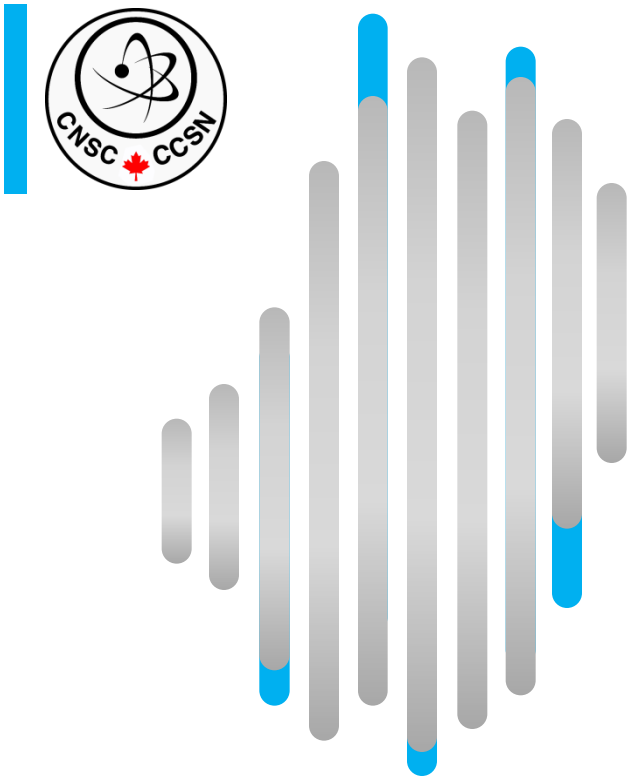


Update on the Development, Deployment and Regulation of Small Modular Reactors

Commission Meeting
August 22-23, 2018
CMD 18-M31

CNSC Staff Presentation

e-Doc 5401043 (PPT)
e-Doc 5605405 (PDF)

Table of Contents

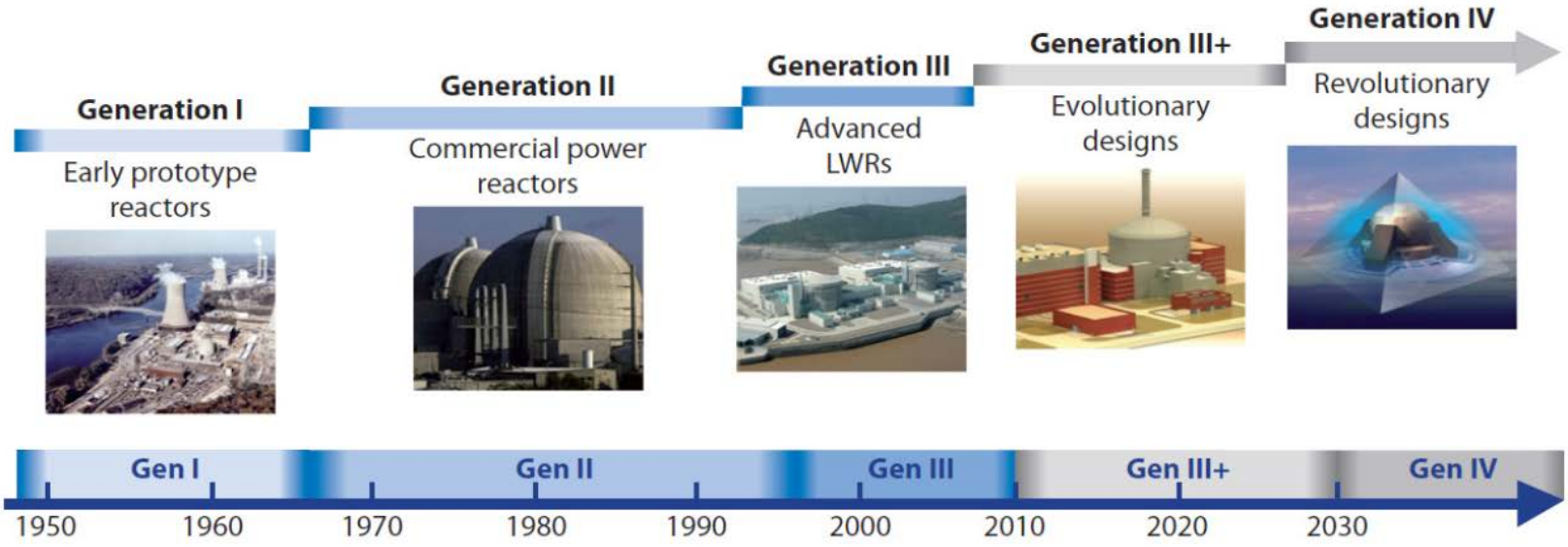
BACKGROUND

Last presentation to the Commission February 5, 2014

CMD 14-M8, *The Evolution of Nuclear Reactor Technologies,* provided to the Commission for information

- Overview of Generations I to IV and how safety considerations were reflected in the design
- Discussion on what Small Modular Reactors (SMRs) are and what they mean from a regulatory standpoint
- Overview of the CNSC's Vendor Design Review Process

Technology Evolution



Regulatory Approach

- Objective based with few prescriptive requirements
- More prescriptive
  More regulatory certainty
- New safety claims and no operational experience – return to objective based?

Small Modular Reactors (SMRs)

- “SMR” is generally used as a marketing term
- Vendors are proposing alternative approaches for design and deployment that depart from tradition
- Many will employ multiple novel technological approaches:
  - passive safety features
  - extensive use of factory-built modules
  - fewer staff on site compared to traditional reactors

Deployment Strategies

Examples of different deployment strategies include:

- Security by design
- Remote operation
- Transportable / relocatable cores
- Extensive use of factory-constructed facility / reactor modules

Proponents need to address all Safety and Control Areas and demonstrate that there is adequate defence-in-depth

Building on the past while looking to the future

- Many Gen IV designs are based on concepts that were originally developed in the 1950's to 1970's
- Each technology presents new approaches and innovative features that need to be proven
  - different reactor cores, fuel types, configurations and levels of enrichment (e.g., graphite moderator or molten fuels)
  - different ways to cool the core (e.g., molten lead, gas, sodium & molten salts)
- New technologies have potential advantages over existing designs (e.g., passive design)

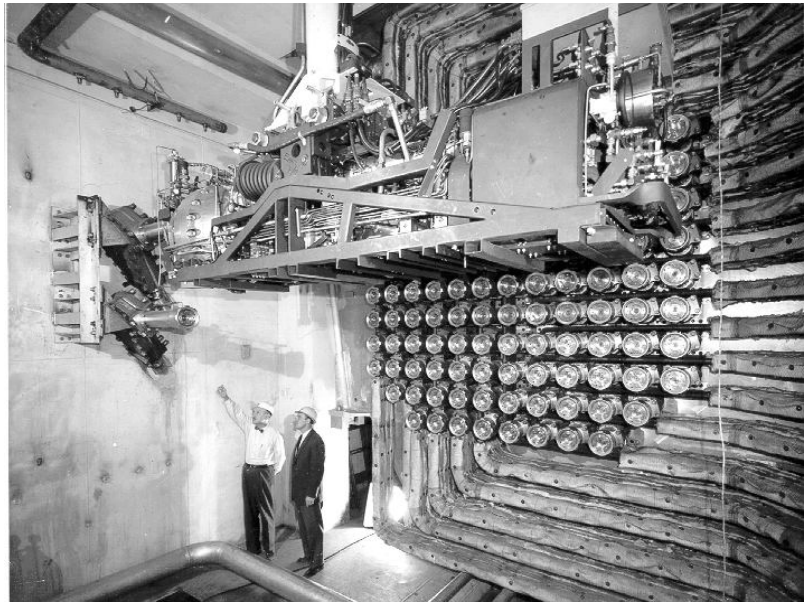
Processes are in place to ensure safety

Global Context

- The International Atomic Energy Agency considers an SMR to be “reactors that produce electricity of up to 300 MW(e)”
- Advances in methods of analysis and materials-sciences mean that these designs are potentially becoming achievable now
- Proponents are reinvigorating non-water cooled reactor technologies
- Capacity for power generation where traditional plants are not practical or required

Significant national and international interest to address climate change

Early Canadian Designs

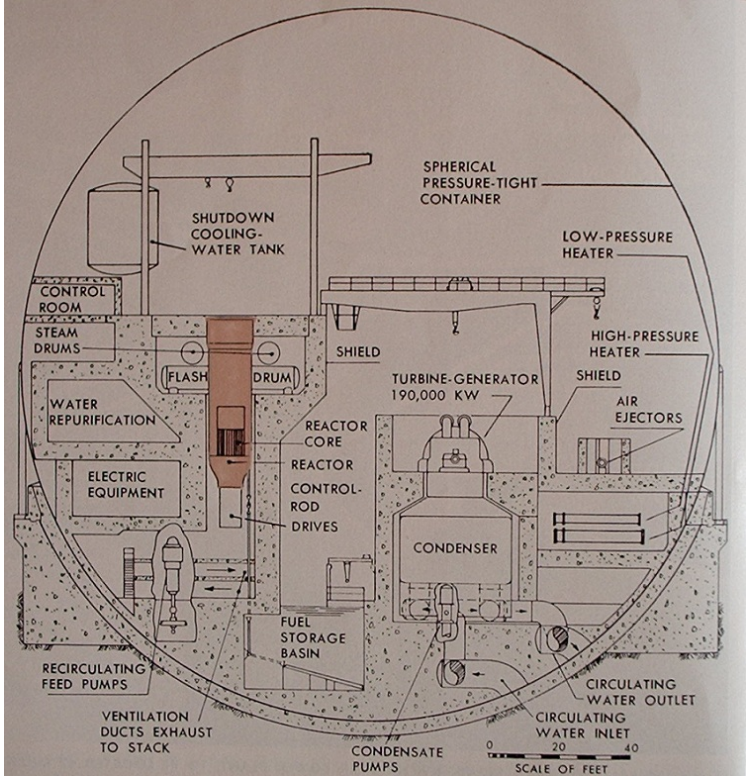


- Nuclear Power Demonstration (NPD)
  - 1962 to 1987
  - 22 MWe, Pressurized Heavy Water Reactor (CANDU)

- Douglas Point Generating Station
  - 1968 to 1984
  - 220 MWe, Pressurized Heavy Water Reactor (CANDU)

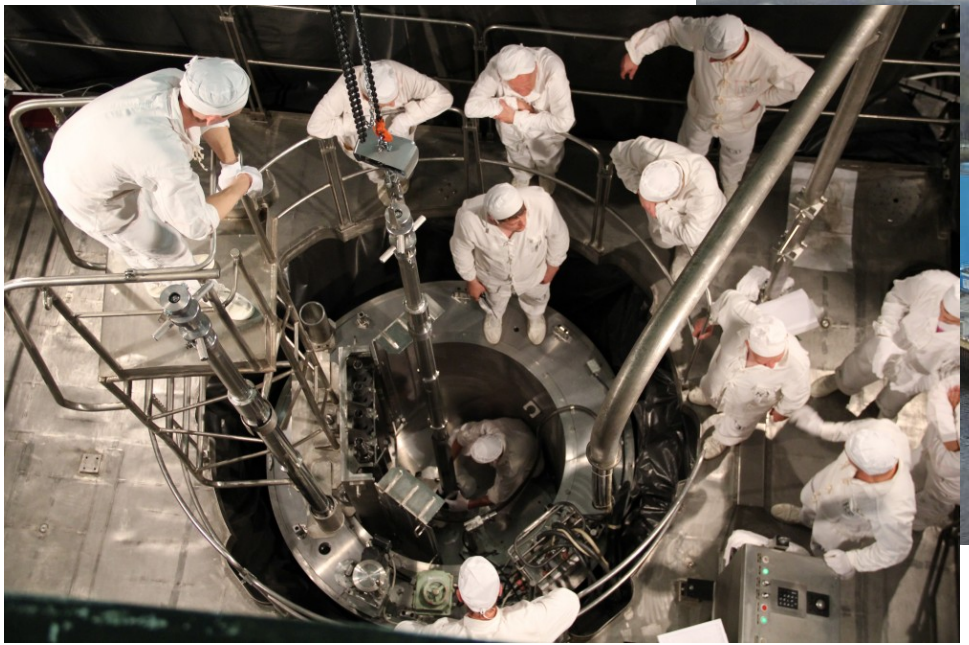
Early International Designs

- Calder Hall, UK
  - 1956 to 2003
  - 4 units at 60 MWe each, gas-cooled



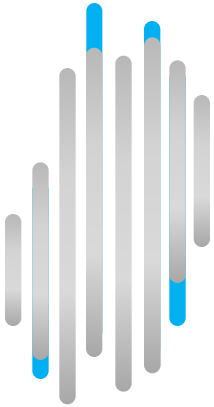
- Dresden Unit 1, USA
  - 1960 to 1978
  - 210 MWe, Boiling Water Reactor

Akademik Lomonosov, Russia



(Photos courtesy of Rosenergoatom)

- July 2018 onwards
- 2 units at 35MWe each, water-cooled



NATIONAL SCAN – RECENT DEVELOPMENTS

Federal Activities

- Government of Canada responds to House of Commons Standing Committee report agreeing to support the development of SMRs (October 2017)
- Natural Resources Canada now facilitating the *Canadian SMR Roadmap* (Report to Cabinet October 2018)
  - CNSC is participating in our role as the nuclear regulator – observing and providing clarifications on technical and regulatory issues

Provincial & Territorial Activities

- Ontario Ministry of Energy *Feasibility of the Potential Deployment of Small Modular Reactors (SMRs) in Ontario*
- Established electrical utilities:
  - are interested in becoming SMR operators in Canada
  - are providing advice to SMR vendors
  - have introduced a new CANDU Owner's Group (COG) forum to discuss SMR issues

OPG to Seek Pan-Canadian Small Modular Reactor Strategy to Fill 2030 Supply Gap

"Ontario Power Generation [OPG] plans to fill a predicted supply gap in the 2030s with new nuclear capacity and the utility is collaborating with Saskatchewan on the potential for a Pan-Canadian fleet of Small Modular Reactors" OPG's Vice President of Strategy & Acquisitions, 2017

Canadian Nuclear Laboratories (CNL) Activities

Positioning itself to provide science and technology services

- Engaged with SMR vendors for a wide range of activities
- Stated goal to 'host an SMR on a CNL site by 2026'

Request for Expression of Interest: CNL's SMR Strategy

- Sought to better understand market demands for activities related to SMRs
- Vendor, utility, and provincial government interest

CNL's *Invitation for SMR Demonstration Projects*

- A number of proponents responded

CNSC: Informing Stakeholders (1/3)

Stakeholders:

- Want to understand the Canadian regulatory environment – they have questions about how to engage the CNSC and our regulatory approach, including the licensing process

CNSC staff are:

- Explaining how existing regulatory framework tools can be used
- Explaining the principles of our requirements such as defence-in-depth, safety margins and graded approach

CNSC staff are actively engaging with stakeholders to ensure expectations are clear

CNSC: Informing Stakeholders (2/3)

CNSC has been engaging stakeholders through:

- Vendor design reviews
- Pre-licensing on prototypic facilities
- Discussions on deployment of SMRs
- Workshops and participation in conferences
- Presentations to municipalities and the public

CNSC Staff are listening and considering feedback from stakeholders

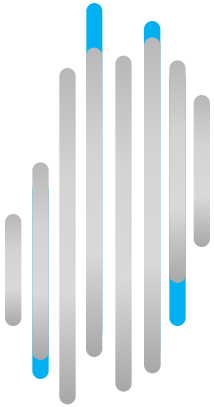
CNSC: Informing Stakeholders (3/3)

- Published *Small Modular Reactors: Regulatory Strategy, Approaches and Challenges* and the *What We Heard Report*
- SMR Licence Application Guide (LAG) – seeking public consultation July 2018
- Current focus: Challenges arising from novelties in design (pre-licensing)
- Focus will change as units are deployed
  - first units are likely to be prototypes or demonstration facilities on a “controlled” site
  - deployment of “standardized” units will face different challenges

CNSC’s existing regulatory requirements are suitable for regulating SMR activities

Vendor Activities

- Vendors are engaging with the CNSC in vendor design reviews in preparation for possible deployment in Canada
  - seeking to familiarize themselves with Canadian regulations and licensing processes
  - expressing their intent to comply with requirements
- Vendors are actively engaging with existing Canadian nuclear utilities for support in their VDRs and looking forward to future operations



CNSC INTERNATIONAL ENGAGEMENT

International Cooperation

- International fora allow us to discuss common issues, share information and develop common positions
- Leads to more efficient and effective technical assessments
- Provides input to licensing and compliance framework to ensure international bench-marking and continuous improvement
- Sharing resources in the conduct of regulatory R&D

International Engagement

- Nuclear Energy Agency:
  - Multinational Design Evaluation Program (MDEP)
  - Group on the Safety of Advanced Reactors (GSAR)
  - Working Group on the Regulation of New Reactors (WGRNR)
- Bilateral arrangements with other nuclear regulators
- International Atomic Energy Agency (IAEA)
  - exploring implications of SMRs on existing requirements

Co-operation on Technical Reviews

- Working with other nuclear regulators internationally to exchange unclassified technical information and cooperate on items such as:
  - design, siting, construction, commissioning, operation, and decommissioning
  - legislation, regulations, licences, regulatory codes, standards, criteria and guides
  - technical reports and nuclear safety assessments, including those related to radiological safety

IAEA SMR Regulators' Forum

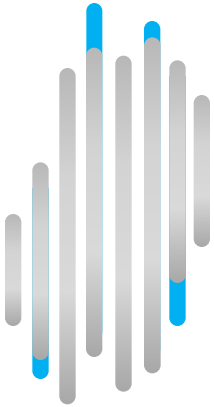
" to identify, understand and address key regulatory challenges that may emerge in future SMR regulatory discussions. This will help enhance safety, efficiency in licensing and enable regulators to inform changes, if necessary, to their requirements and regulatory practices"

IAEA
International Atomic Energy Agency

IAEA SMR Working Groups

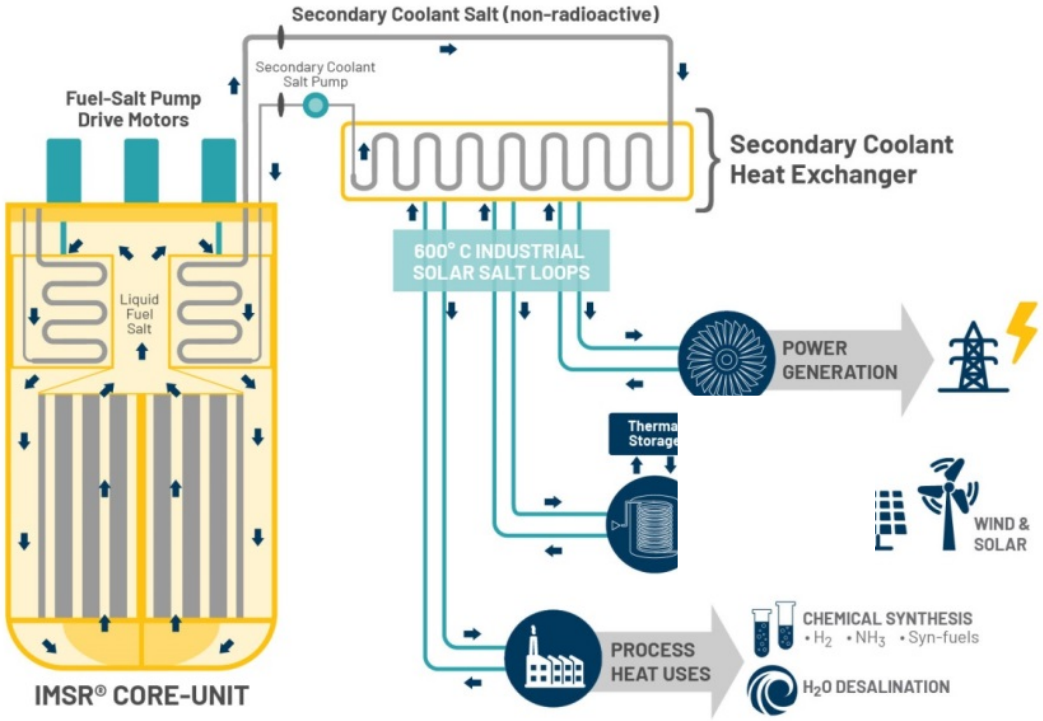
- Understand impacts of novelties on existing frameworks and develop common positions

2015-17 (Pilot)	2017-2020 (Focus on Near-Term Licensing)
1. Emergency Planning Zones 2. Application of Defence-in-Depth 3. Application of Graded Approach	1. Licensing Issues (including demonstration plants, and human factors) 2. Design and Safety Analysis Issues 3. Manufacturing, Construction and Commissioning Issues



OVERVIEW OF SMR TECHNOLOGIES

Molten Salt Reactor

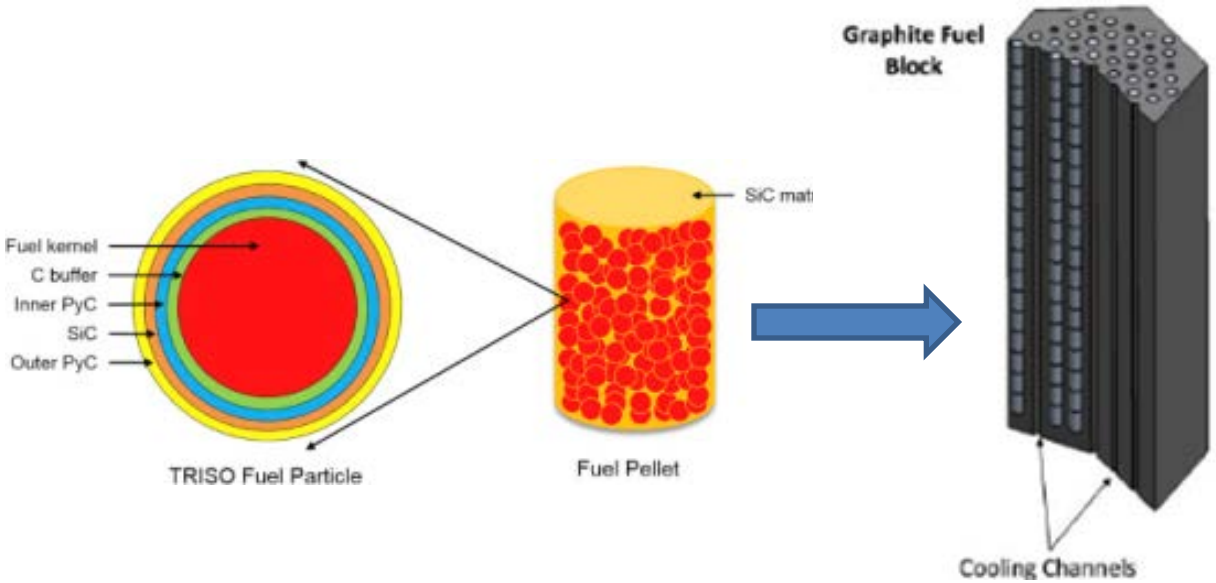


(*Courtesy of Terrestrial Energy*)

Typical Features

- Molten salt coolant
- Molten salt or solid fuel
- Graphite moderated or fast neutron spectrum reactor

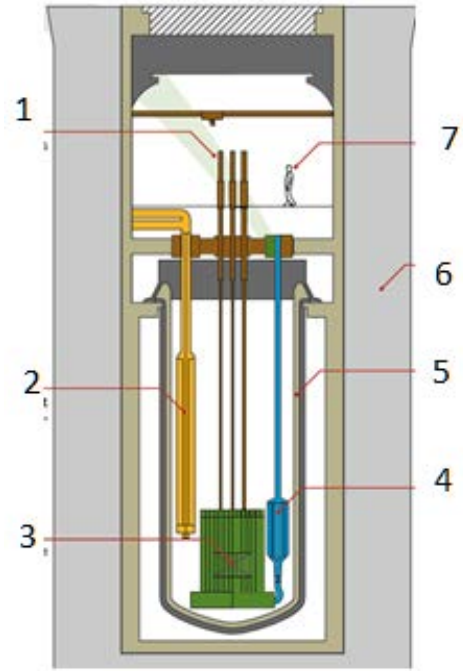
High Temperature Gas Reactor



Typical Features

- Helium cooled
- TRISO fuel
- Graphite moderated

Liquid Metal Cooled Reactor



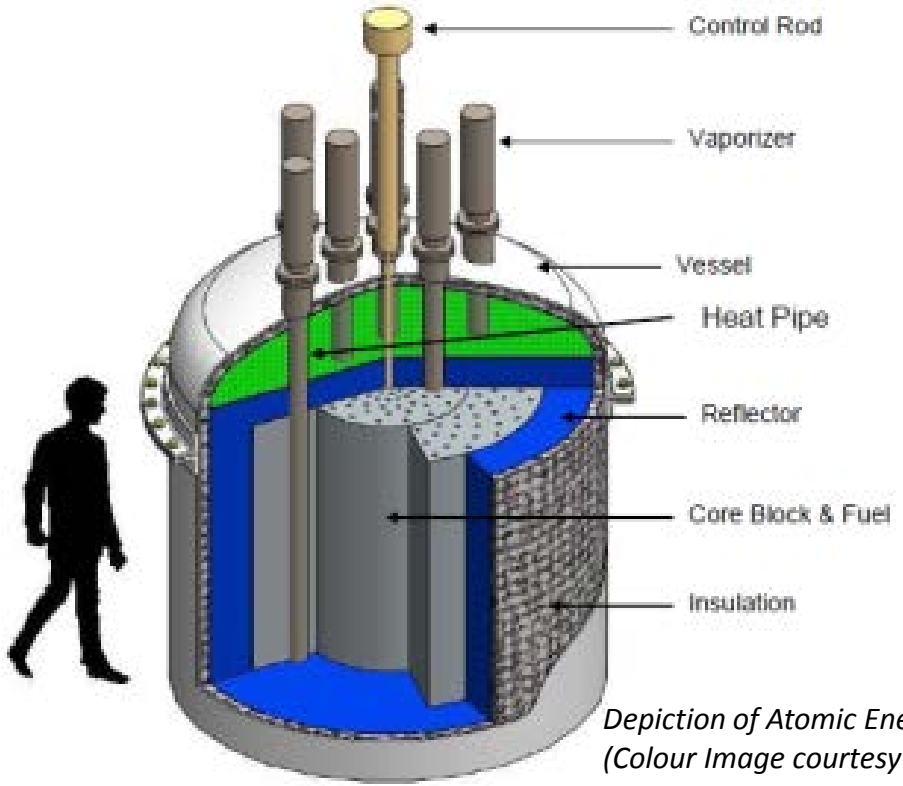
1) Control rods
2) Heat exchanger
3) Reactor Core
4) Pump
5) Reactor vessel
6) Concrete
7) Human scale

Typical Features

- Sodium, lead or bismuth cooled
- Metal or ceramic fuel
- Fast reactor – no moderator

(Courtesy of Advanced Reactor Concepts Nuclear)

Solid State or Heat Pipe Reactor



Depiction of Atomic Energy of Canada's Nuclear Battery Concept, 1988
(Colour Image courtesy of Dunedin Energy Systems)

Typical Features

- Cooling via heat pipes
- Solid Fuel – various types
- Graphite moderated
- Very few moving parts

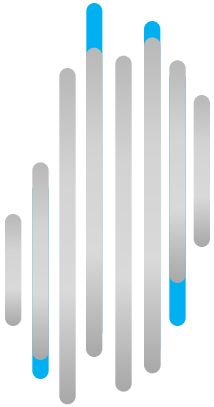
Potential Safety Features

Many of the new designs are aiming to include the following safety features:

- Power level self-regulated through inherent reactivity feedback
- Passive heat removal systems (protecting primary coolant and core from overheating)
- Fuel highly resistant to high temperature events and with stronger fission products retention
- Relatively long grace time for operator action during and after events

Regulatory Areas of Interest

- Demonstration of novel safety features and their limits (e.g., new concepts for passive safety systems will have to be proven)
- Understanding the long term performance of new materials with limited operational experience
- Understanding how in-service inspections will be addressed for integral reactors



Commission Meeting August 22-23, 2018, CMD 18-M31

VENDOR DESIGN REVIEW UPDATE

Status of Vendor Design Reviews

No.	Country of origin	Company (Design)	Reactor Type	Elec. Output per unit	Status
1	Canada - U.S.	Terrestrial Energy (IMSR-400)	Molten salt (graphite moderated)	200 MWe	PHASE 1 - Completed PHASE 2 - Service Agreement signed
2	U.S.- Korea - China	Ultra Safe Nuclear (MMR-5)	High-temperature gas cooled (graphite moderated)	5 MWe	PHASE 1 - Near completion PHASE 2 - Service Agreement signed
3	Sweden - Canada	LeadCold (SEALER)	Liquid metal cooled - Lead (no moderator - fast spectrum)	3 to 10 MWe	PHASE 1 - On hold at vendor's request
4	U.S.	Advanced Reactor Concepts (ARC-100)	Liquid metal cooled - Sodium (no moderator - fast spectrum)	100 MWe	PHASE 1 - In progress
5	U.K.	Urenco (U-Battery)	High temperature gas cooled (graphite moderated)	4 MWe	PHASE 1 - Service Agreement under development
6	U.K.	Moltex Energy (SSR-W300)	Molten salt (no moderator - fast spectrum)	300 MWe	PHASE 1 - In progress
7	Canada - U.S.	StarCore Nuclear	High-temperature gas cooled (graphite moderated)	20 MWe	PHASE 1 & 2 - Service Agreement under development
8	U.S.	SMR LLC - a Holtec International Company (SMR-160)	Pressurized water (light water moderated - PWR)	160 MWe	PHASE 1 - In progress
9	U.S.	NuScale Power (NuScale)	Pressurized water (light water moderated - PWR)	50 MWe	PHASE 2*- Service Agreement under development
10	U.S.	Westinghouse Electric (eVinci)	Heat pipe / Nuclear battery (yttrium hydride moderated)	< 25 MWe	PHASE 2*- Service Agreement under development

* Phase 1 objectives will be addressed within the Phase 2 scope of work

Vendor Designs Reviews (VDR)

- Stakeholders are encouraged to engage with the CNSC early
- A VDR is an optional process that:
  - provides feedback on vendor's efforts to address Canadian requirements
  - promotes early identification of key issues and obstacles to licensing
  - identifies important vendor and CNSC research activities
  - provides an opportunity for CNSC staff to become familiar with the design
- A VDR does not constitute an approval of a design

VDR Framework

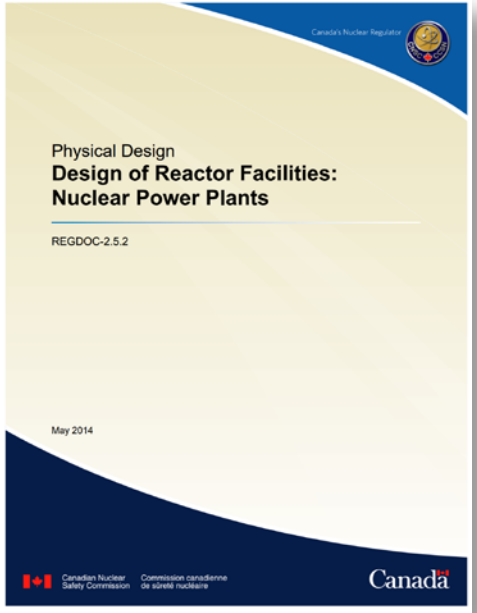
- The VDR process is described in GD-385, *Pre-licensing Review of a Vendor's Reactor Design*
  - covers standardized design topics such as reactor core, fuel, controls, containment, human factors, security, decommissioning, etc.
- A VDR focuses on design and safety analysis and the managed processes supporting these activities

The 3 VDR Phases

- Phase 1
  - determines if the vendor understands and intends to meet CNSC design requirements
- Phase 2
  - focus on identifying potential fundamental barriers to licensing
- Phase 3
  - involves follow up on one or more focus areas chosen by the vendor

VDR Insight for the Regulatory Framework

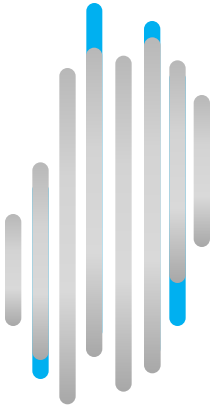
- The current regulatory framework can be used for new technologies
- Alternative approaches are being proposed and may influence continuous improvements to the regulatory framework
- Reviews are having positive impacts on the vendors' design processes, including the management systems and R&D programs



VDR in summary

The VDR process:

- Clarifies and reinforces CNSC's regulatory requirements and expectations
- Uses a technology neutral and consistent process for all vendors
- Provides regulatory feedback early on in the design process
- Helps vendors in assessing deployment readiness of their technology
- Informs the licensing process and results in better licence applications
- Allows the CNSC to prepare for a licence application



STRATEGY FOR READINESS

CNSC Strategy for Readiness

Increased regulatory certainty

- fairness, rigour, efficiency, transparency

Establishment of technical readiness

- knowledge and capacity, enabling processes

Establishment of priorities

- what needs to be done and by when

Increased awareness

- internally and with external stakeholders

Elements of Strategy

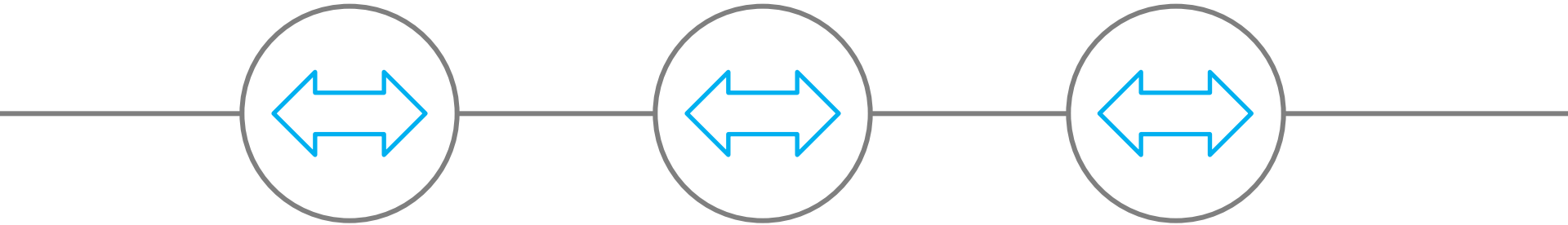
Provide Leadership and Coordination

Small Modular Reactor Steering Committee (SMRSC)

Chaired by:
Executive Vice-President and Chief Regulatory Operations Officer

Elements of Strategy

Established processes for enabling decisions regarding the regulation of SMRs



Regulatory framework

Nuclear Safety and Control Act (NSCA), regulations, licences, regulatory documents

Risk-informed processes

Managed processes covering strategic decision making

Pre-licensing and licensing compliance

Capable and agile staff

Capacity/capability

Training

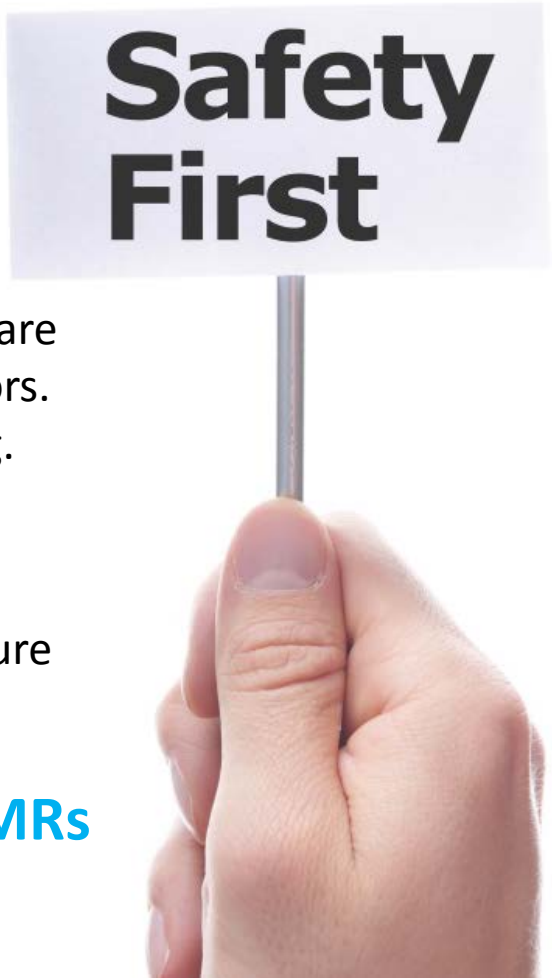
International cooperation

Elements of Strategy

Communicate

Conclusions

- The CNSC's regulatory framework is robust, flexible and based on decades of operating experience and can be applied to advanced reactor technologies
- The CNSC's regulatory framework and internal processes are risk-informed and can be used to licence advanced reactors. It allows for proposing alternatives and the use of grading.
- Vendor design reviews are a well respected and useful service
- CNSC staff are actively engaging with stakeholders to ensure clarity of requirements and expectations



The CNSC is ready and capable to licence SMRs

ANNEX

- DIS-16-04, *Small Modular Reactors: Regulatory Strategy, Approaches and Challenges*
  - What We Heard Report

http://nuclearsafety.gc.ca/eng/acts-and-regulations/consultation/history/dis-16-04.cfm

nuclearsafety.gc.ca