SAFETY AND LICENSING CONSIDERATIONS FOR SMRs – INTERNATIONAL EXPERIENCE AND CANADIAN CONSIDERATIONS

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ABSTRACT

The Canadian market has a number of potential applications for small modular reactors in industries such as mining, oil and gas, and defense where power demand is often in remote locations not easily serviced by the electrical grid.

Since Canada has a long history of nuclear power regulation (including small reactors) and has developed regulatory documents for small reactors, there is high potential for SMRs to be successfully licensed, designed, built, and operated.

This paper summarized Canadian and International experience with small reactors. It also summarizes safety and licensing considerations from this experience.

1. Introduction

Recently, there has been a renewed interest throughout the world in small modular reactor (SMRs) units for generating electricity and for other applications. SMRs can be a good fit in markets where anticipated electricity demand is projected to increase incrementally because SMRs could be built in series as needed. In addition, SMRs can be used in applications where access to electrical transmission grids is not available or cost prohibitive.

Small reactors can also make economic sense because of the high cost of diesel generation compared to the low marginal cost of producing electricity from nuclear energy.

Canada provides some potential applications for mine sites, oil sands, and defense applications in the Northern regions. Another benefit for the aforementioned applications is that much of the qualified engineers and skilled craft workers needed to construct larger reactors are occupied by the primary industry (mining, oil and gas); SMRS tend to be prefabricated with much less on site labour requirements.

2. International Experience of SMRs

2.2.1 Canadian Experience

Canada has a long history with design, build, operation, and licensing of small research reactors. A representative list is provided in Table 2.2.1.

Table 2.2.1: Canadian Small Research Reactors [4]

Reactor	In Service	Output	Use
ZEEP (Zero Energy Experimental Pile)	**1945**	**10-Watts**	First nuclear chain reaction outside the United States, heavy-water-moderated fuel lattices for CANDU designs.
1947 - NRX (National Research Experimental)	**1947**	**42MWt**	Fuel development, materials, neutron beams
1957 - PTR (Pool Test Reactor)	**1957**	**10kW(t)**	Used 93% enriched uranium-aluminum plate-type fuel. Research - burn up measurement of fissile samples from NRX.
1960 - ZED-2 (Zero Energy Deuterium-2)	**1960**	**200 W**	Research - measurements on larger, more representative CANDU lattices, effects of heavy water and alternative light water and organic coolants.
NRU (National Research Universal)	**1957**	**200 MWt**	Research: Fuel development, material testing, Medical Isotopes
Whiteshell-1	**1965**	**60MWt**	Test reactor for the proposed organic-cooled CANDU power reactor, irradiation and fuel testing
SLOWPOKE-2 (Safe Low Power Critical Experiment)	**1968**	**20 kWt**	Neutron activation analysis, trace radioisotope production, training

2.2.2. International Experience

A wide variety of SMR designs have been proposed globally. Many of these proposed designs are listed in Figure 2.2.1, along with an indication of their net electric output (MWe) and their projected refueling cycle.

As can be seen in Figure 2.2.1, three main categories are being proposed: light water reactors, graphite-moderated high temperature reactors, and fast neutron reactors. The first has the lowest technological risk, but the second (high-temperature reactors) offers many applications that the lower-temperature light-water reactors cannot fulfill, while the third (fast neutron reactors) can be smaller, simpler and with longer operation before refueling. Appendix A provides additional details regarding these SMR designs.

Figure 2.2.1 Summary of SMR Technologies

Name	MWe	Type[a]	Refueling Cycle	Developer
Radix	10	PWR	10 years	Radix Power, USA
CAREM	27	PWR	1 year	CNEA and INVAP, Argentina
KLT-40S	35	PWR	2 to 3 years	OKBM, Russia
NuScale	45	PWR	24 months	NuScale Power, USA
SMART	100	PWR	3 years	KAERI, South Korea
CAP-100/ACP100	100	PWR	24 months	CNNC & Guodian, China
SMR LLC	160	PWR	3 years	Holtec, USA
mPower	180[b]	PWR	4 years	Generation mPower, USA
Westinghouse SMR	225	PWR	24 months	Westinghouse, USA
VK-300	300	BWR	1 year	Atomenergoproekt, Russia
HTR-PM	2x105	HTR	NR	INET, China
EM2	240	HTR	Up to 30 years	General Atomic, USAs
SC HTGR	250	HTR	NR	AREVA, France
4S	10	FNR-Na	30 years	Toshiba, Japan
PRISM	311	FNR-Na	12 to 24 months	GE-Hitachi, USA
Gen4	25	FNR-PbBi	10 years	Gen4 Energy, USA
SVBR	100	FNR-PbBi	7 to 8 years	AKME-engineering, Russia

NR = Not reported;
[a]PWR = Pressurized-Water Reactor; BWR = Boiling-Water Reactor; HTR = High-Temperature Reactor; FNR-Na = Sodium-Cooled Fast Neutron Reactor; FNR-PbBi = Lead-Bismuth Eutectic Fast Neutron Reactor.
[b]With water-cooled condenser. 155 Mwe with air-cooled condenser.

The most developed SMR projects are in Russia, China and Korea. Currently, there are four small reactors operating in a remote area of Siberia that produce steam for district heating and electricity (11 MWe each). A floating barge equipped with two small reactors under construction in Russia, with operation expected in 2013 near the city of Viluchinsk.

In China, Chinergy is building the 210 MWe HTR-PM, which consists of twin 250 MWt reactors. China National Nuclear Corporation (CNNC) has been developing the ACP100 modular design, which is a 100 to 150 MWe pressurized water reactor designed for electricity, heat, or desalination. Construction of the first units is expected to begin by the end of 2013.

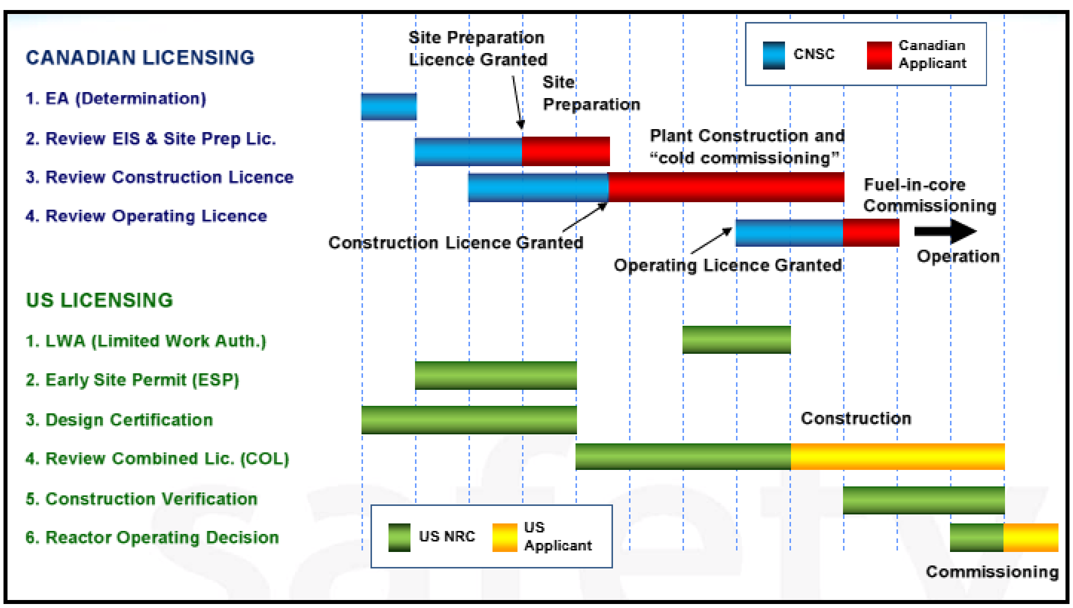
South Korea's SMART (System-integrated Modular Advanced Reactor) is a 330 MWt pressurised water reactor with integral steam generators and advanced safety features. It is designed by the Korea Atomic Energy Research Institute (KAERI) for generating electricity (up to 100 MWe) and/or thermal applications such as seawater desalination. Design life is 60 years, with a three-year refuelling cycle. KAERI is proceeding with licensing the design with a view to building a 90 MWe demonstration plant to operate from 2017. The Nuclear Safety and Security Commission (NSSC) granted approval at July 4, 2012, for a standard design for the SMART reactor.

United States experience of small light water reactors has been of very small military power such as the 1.5 MWe PM-3A reactor that operated at McMurdo Sound in Antarctica from 1962-72, generating a total of 78 million kWh. There was also an Army program for small reactor development, most recently the DEER (deployable electric energy reactor) concept. DEER would be portable and sealed, for forward military bases. Successful small reactors were constructed in the 1950s, including Big Rock Point, a BWR of 67 MWe, which operated for 35 years to 1997. There is now a revival of interest in small LWRs in the US. The U.S. Nuclear Regulatory Commission (NRC) expects to receive applications for staff review and approval of some of these designs as early as Fiscal Year 2013.

3. Summary of Canadian Regulatory Framework

3.1 Comparison of Canadian and US Licensing Process

Figure 3.1.1: Comparison of Canadian and US Licensing Processes [1]



Small reactor facilities can allow for greater flexibility in the application of the graded approach because they operate at lower power levels where certain scenarios are not possible and therefore limited design or analysis is required. Larger reactors typically have high-power, complex cores and a long list of postulated initiating events that require detailed analysis.

The regulatory documents RD-367, “Design of Small Reactor Facilities”, and RD-308, “Deterministic Safety Analysis for Small Reactor Facilities”, set out the requirements of the CNSC for the design and safety analysis of small reactor facilities. A small reactor facility is defined as a reactor facility containing a reactor with a power level of less than approximately 200 MWth that is used for research, isotope production, steam generation, electricity production or other applications.

3.2 CNSC RD-367

Separate documents, RD-337, “Design of New Nuclear Power Plants”, and RD-310, “Safety Analysis for Nuclear Power Plants”, set out the requirements of the CNSC for the design and safety analysis of larger (>200 MWth) reactors.

RD-367 is technology neutral and includes: safety goals and objectives, safety concepts, safety management principles, design of structures, systems and components, safety, security and engineering aspects of the reactor facility and integration of safety assessments.

3.3 RD-308

RD-308 details the elements of a deterministic safety analysis, which include: the selection of events to be analyzed, acceptance criteria, methods and assumptions, documentation, and quality control. The CNSC allows for the use of a graded approach to reactor design and safety analysis. The graded approach allows requirements to be implemented in a way that the level of design, analysis, and documentation are commensurate with the potential risks posed by the reactor without compromising safety. Factors to be considered when applying the graded approach are:

- Reactor power, safety characteristics, and source terms
- Amount and enrichment of fissile and fissionable material
- Fuel design
- Type and mass of moderator, reflector, and coolant
- Utilization of the reactor
- Presence of high-energy sources and other radioactive and hazardous sources
- Safety design features
- Siting and Proximity to populated areas

The added flexibility in the graded approach could result in shorter durations for licensing. CNSC has estimated the duration for the licensing process for small reactors relative to nuclear power reactors. This could reduce the overall licensing time from 9 years to 6 when compared to NPPs. Table 3.3.1 provides a comparison [1].

Figure 3.3.1: Approximate Durations of Licensing of SMRs [1]

	First of a Kind Small Reactors	First of a Kind NPP
Activity	**Duration**	**Duration**
Environmental Assessment and Licence to Prepare Site (includes development of Joint Review Panel Agreement and EIS Guidelines)	~24 months	~24 months
Licence to Construct – assessed in parallel with EA (and Licence to Prepare Site with SMRs)	~ 30 months	~30 months
Applicant prepares site, constructs facility and conducts Stage A (Fuel-out) Commissioning	~24-36 months	-
Applicant Prepares Site	-	~ 18 months
Licence to Operate	~24 months	~24 months
Applicants Activities, e.g. Plant Construction	-	~48-54 months
Total duration to Licence to Operate	**~6 years**	**~9 years**

7. Conclusions

Canada offers an environment that is suitable for the use of small modular reactors based on the geographic, economic, technical, and political climate. Based on the history of design, construction, operation, and licensing in Canada; coupled with international experience, there is a strong potential for small modular reactors to be deployed.

8. References

[1] T. JAMIESON, Regulating Small Reactors: Canada is Ready, Platts 2nd Annual Small Modular Reactors Conference May 23-24, 2011 Washington, DC.

[2] CNSC RD-308: Deterministic Safety Analysis for Small Reactor Facilities, June 2011.

[3] CNSC RD-367: Design of Small Reactor Facilities, June 2011.

[4] AECL Website, http://www.aecl.ca/NewsRoom/News/Press-2010/101102.htm; accessed 17-Oct-12.

[5] CNS Website, http://media.cns-snc.ca/history/wr-1/wr-1_1.html; accessed 17-Oct-12.