Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 143 (2017) 605–610

Energy Procedia

www.elsevier.com/locate/procedia

World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference, WES-CUE 2017, 19–21 July 2017, Singapore

Global developments in advanced reactor technologies and international cooperation

Victor Nian[a,*]

[a]*Energy Studies Institute, National University of Singapore, Singapore*

Abstract

There have been broadly two waves of nuclear reactor technology developments. The first wave is the construction of the exploratory Generation I and early Generation II reactors in Canada, Russia, the USA, and Western Europe. The second wave is the rapid scale-up of commercially proven Generation II reactors in North America and Western Europe followed by technology transfer to East Asia after the Three Mile Island and Chernobyl accidents. As of today, majority of the reactors in commercial operation belong to the Generation II designs. We are in the third wave which is the development of Generation III and III+ reactors post-Fukushima. The objectives of Generation III/III^{+} reactors are radically enhanced safety and improved economics. The third wave also saw the emergence of East Asian vendors from Japan, South Korea, and China offering indigenous reactors to the global market. Parallel to the developments in the third wave, the nuclear industry seems to have also ventured into the fourth wave, which is the development and early demonstration of Generation IV reactors. Through a review of historical developments in nuclear energy worldwide, this paper provides a perspective of future reactor technology and market developments with a view of the changing dynamics in technology and the global market developments.

Peer-review under responsibility of the scientific committee of the World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference.

Keywords: Generation IV; small modular reactor; new nuclear user state; technology transfer; international collaboration

* Corresponding author. Tel.: +65 66012076.
E-mail address: nian@nus.edu.sg

1876-6102
Peer-review under responsibility of the scientific committee of the World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference.
10.1016/j.egypro.2017.12.734

1. Historical developments

With reference to the International Atomic Energy Agency's Power Reactor Information System database [1], most of the reactors were constructed more than 30 years ago. From the late 1980s to the 1990s, the global market of reactor constructions experienced a major shift from North America and Western Europe to East Asia. The early nuclear reactors constructed in East Asia were supplied by Western vendors, such as Atomic Energy Canada Limited (AECL), Framatome, OKB Gidropress, and Westinghouse. Framatome has become part of Areva whose majority shares are owned by the French state and Westinghouse is now part of Toshiba. Through decades of strategic partnership with these Western vendors, East Asian countries, namely, Japan, South Korea, and China have derived indigenous reactor designs to compete in international markets [2]. With China leading the world in the number of new reactors under construction, several countries in the Middle East, South, and South East Asia are inching towards becoming new nuclear user-states.

Nomenclature

ABWR	advanced boiling water reactor
AECL	Atomic Energy Canada Limited
BDBA	beyond design basis accident
BWR	boiling water reactor
CE	Combustion Engineering (USA)
CGNPC	China General Nuclear Power Corporation
CNNC	China National Nuclear Corporation
ESBWR	economic simplified boiling water reactor
FNR	fast neutron reactor
HTR	High temperature reactor
HTR-PM	high temperature reactor pebble-bed module
HWR	heavy water reactor
iPWR	integral pressurized water reactors
KSNP	Korean Standard Nuclear Plant
LFR	liquid-metal-cooled fast reactor
MHI	Mitsubishi Heavy Industry (Japan)
MSR	molten salt reactor
NRC	Nuclear Regulatory Commission (USA)
SMR	small modular reactor
SNERDI	Shanghai Nuclear Engineering Research and Design Institute
SNPTC	State Nuclear Power Technology Corporation

1.1. USA and France

Majority of the nuclear reactors in commercial operation are Generation II pressurized water reactors (PWRs), boiling water reactors (BWRs), and heavy water reactors (HWRs) (see Table 1 for examples of Generation II reactors). Studies by Koomey and Hultman [3] and Lovering, Yip and Nordhaus [4] suggest the Three Mile Island accident as an important factor in the cost escalations narratives, including new regulatory safety requirements, licensing, back-fit requirement, and uncertainties post-accident [5-7]. Standardization in design and construction serves as an important basis for technology competence development in France. Framatome derived indigenous designs of three homogeneous series, namely CP (3-loop 900 MWe class), P/P'4 (4-loop 1300 MWe class), and N4 (4-loop 1450 MWe class) series based on a single Westinghouse platform technology [8]. Despite the multiple benefits of standardization and cost-savings through the twin-unit construction practice Plante [8], there has been mild escalation in reactor construction costs to rising labor costs, increased regulatory requirements, and increased complexity from 900 MWe