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Looking ahead at reactor development

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ABSTRACT

This paper provides a historical overview of the development of advanced reactors, with a focus on Generation IV reactors and the unique international cooperative R&D framework that was put in place within the Generation IV International Forum. Drawing on the expertise developed at the Nuclear Energy Agency, the paper analyses the challenges for deploying advanced reactors in future energy markets, including evolving market requirements and economic considerations, regulatory challenges, research infrastructure needs and human resource issues. The paper concludes on the role of nuclear research and innovation to ensure the conditions for successful deployment of advanced reactors and competition with alternative technologies.

1. Advanced reactors

The use of the term “Advanced Reactors” in the community of nuclear research has a complex background. Early in the development of nuclear reactors, a range of concepts and configurations were considered and tested. Many of the concepts considered “advanced reactors” today have roots and, in some cases, were deployed in prototype form many decades ago. The U.S. Experimental Breeder Reactor I, a liquid metal-cooled reactor that used plutonium fuel, began producing electricity in 1951. Many other technologies, ranging from gas-cooled reactors, molten salt fuel systems, and supercritical water reactors have all been tested in by laboratories in many countries.

Prompted by successful demonstrations of water-cooled reactor technology, such as the Shippingport Atomic Power Station, the world generally came to commercial deployment of nuclear energy around designs of nuclear power plants using mostly light water, but also heavy water. Other approaches remained the subject of research and development.

Water–cooled reactor systems have been extraordinarily successful around the world. Today, conventional water cooled reactor systems comprise the largest source of clean electricity generation in OECD countries and the second largest such source in the world after hydroelectric power. Moreover, new water-cooled technologies available today represent significant improvements in safety and efficiency.

Nevertheless, it is also the case that the markets and operating environment for energy production are evolving. In the past, the absolute cost of nuclear construction was somewhat less important than the long-term reliability it provided; mostly because electricity demand was seen as a factor that would always increase. In many developed countries, economic growth has slowed considerably and energy-intensive heavy industries have given way to service and knowledge-based industries. Growth in electricity demand in these countries is far lower than in countries such as China and India. Further, the cost of constructing and operating new nuclear plants is under tremendous scrutiny in the shadow of recent financially-prompted plant closures and cost overruns in highly visible construction projects.

Additionally, expectations for nuclear safety have risen considerably in the aftermath of the Fukushima Daiichi accident in March 2011; market prices for electricity in many countries have become highly uncertain with the advent of various well-intentioned but disruptive governmental actions and the accelerating introduction of state-supported wind and solar capacity; fossil fuel (coal and gas)

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[3] The NEA is the association of 31 countries that represent the most advanced nuclear technology, safety, and science infrastructures in the world. NEA facilitates cooperation among its members and strategic partners such as China to address complex issues associated with the beneficial use of nuclear technology.

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prices have also dropped, especially due to the development of non-conventional gas resources in some countries, impacting the profitability of nuclear power plant operation; governments around the world have struggled to meet their commitments regarding the disposal of spent nuclear fuel; and while civilian nuclear power plants present no significant technical risk of nuclear proliferation, some suspect a few governments might use civilian nuclear activities to cloak covert weapons programs.

These headwinds have developed at the same time as important factors encourage a greater use of nuclear energy. Notably, governments of the world have indicated a desire to reduce emissions of carbon dioxide; the agreement implementing the outcomes of the 2015 Paris Climate Conference of the United Nations Framework Convention on Climate Change is the most salient indication of these policies. The need to reduce significant air pollution levels in large urban areas, for instance in China or India, is also a driver for deploying “clean air” technologies such as nuclear energy. Further, concerns about energy security and reliability have become a central interest for many countries, particularly those working toward improving the quality of life for their citizens.

The desire to find technology solutions to address the challenges while enabling nuclear energy to play a global role in the future, ever-evolving energy picture has sparked a new spirit of innovation and exploration, with several countries and numerous small companies attempting to bring new concepts to the fore.

As the next steps in the development of nuclear energy are considered, light water reactor (LWR) technology continues to play a prominent role. The development of various small modular reactors (SMRs) is continuing and, in contrast to many of the organisations pursuing the development of Generation IV systems, SMR technologies are receiving very substantial resources and investment from large industrial companies; a factor which improves the prospects for commercialisation in the foreseeable future.

Some light water SMR technologies seem likely to reach the market in the next several years and a few show considerable promise by giving ultimate expression to passive safety design approaches. Some SMRs could provide for more efficient and flexible operations and could prove more readily able to coexist with wind and solar technology in today's intensively cost-focused economic and market models.

However, even these advanced technologies do not address fully all of the safety, economic, nuclear waste, sustainability, and non-proliferation issues associated with the water-cooled reactor based nuclear industry. Some of these concerns become relevant only when very long time frames are considered or if use by developing countries are an important goal for designers. It is for these reasons that researchers and developers around the world devote their energies to the development of Generation IV nuclear energy systems.

2. Generation IV technology and the generation IV International Forum

The term “Generation IV” was coined to differentiate advanced light water reactors, including small modular reactors using light water (i.e., Generation III or III + technologies; see Fig. 1), from a set of technologies judged to have the promise to surpass light water technology in safety, economics, and other measures to be discussed later. Generation IV systems are not designated as such simply because of the coolant they apply; they ideally incorporate engineering features and strategies that allow them to address fully the concerns highlighted in the previous section.

At the end of 2016, 55 out of the 61 reactors under construction were of LWR technology (mostly Generation III/III + designs), and

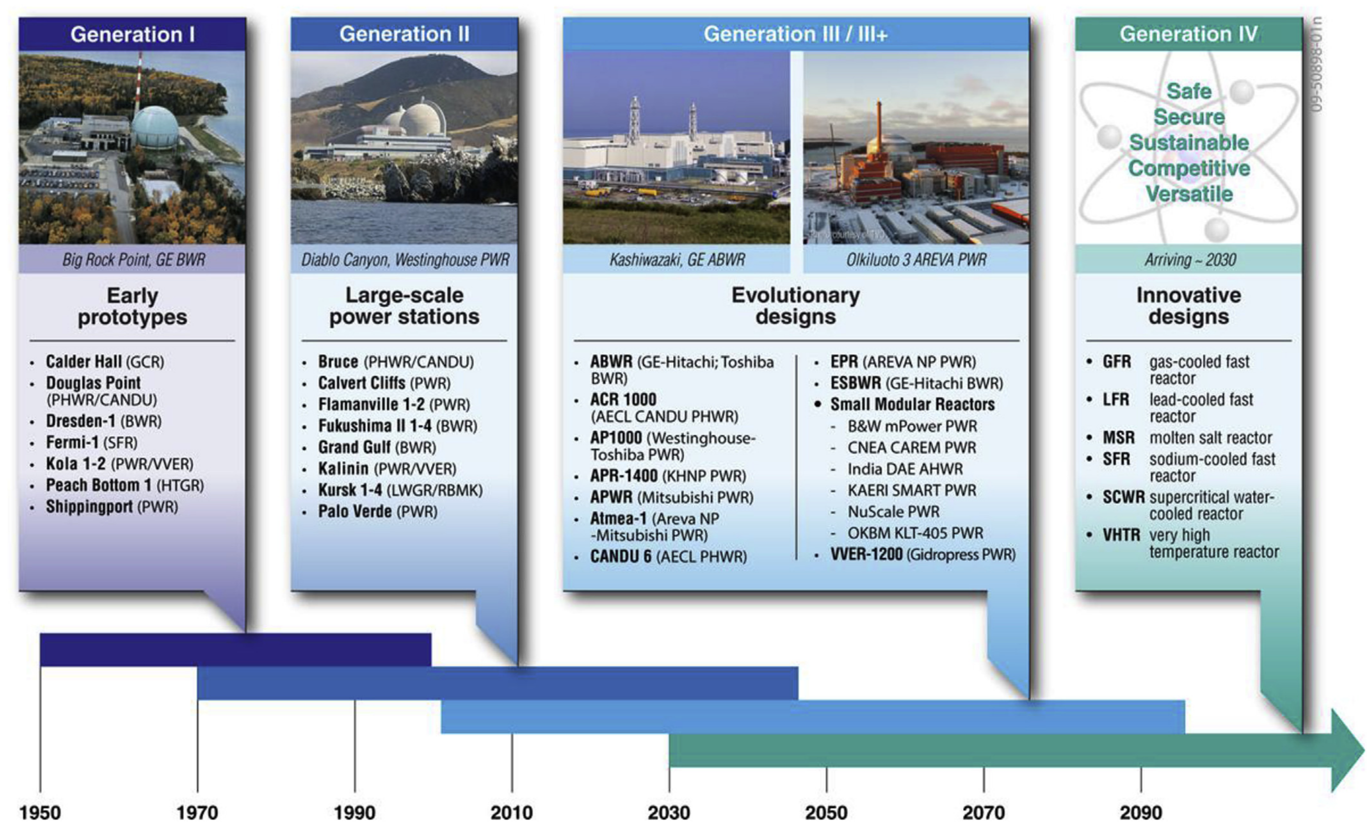

Fig. 1. Evolution of fission reactor technology (www.gen-4.org).

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