Energy Policy 37 (2009) 5149–5166

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Nuclear power for sustainable development: Current status and future prospects

A. Adamantiades [a], I. Kessides [b,*,1]

[a] ICG Aeolian Energy, 1600 K Street, N.W., Washington, DC, USA
[b] The World Bank, 1818 H Street, N.W., Washington, DC, USA

ARTICLE INFO

Article history:
Received 2 November 2008
Accepted 21 July 2009
Available online 18 September 2009

Keywords:
Nuclear power
New reactor technologies
Nuclear accidents

ABSTRACT

Interest in nuclear power has been revived as a result of volatile fossil fuel prices, concerns about the security of energy supplies, and global climate change. This paper describes the current status and future plans for expansion of nuclear power, the advances in nuclear reactor technology, and their impacts on the associated risks and performance of nuclear power. Advanced nuclear reactors have been designed to be simpler and safer, and to have lower costs than currently operating reactors. By addressing many of the public health and safety risks that plagued the industry since the accidents at Three Mile Island and Chernobyl, these reactors may help break the current deadlock over nuclear power. In that case, nuclear power could make a significant contribution towards reducing greenhouse gas emissions. However, significant issues persist, fueling reservations among the public and many decision makers. Nuclear safety, disposal of radioactive wastes, and proliferation of nuclear explosives need to be addressed in an effective and credible way if the necessary public support is to be obtained.

1. Introduction

In recent years there has been a resurgence of interest in developing nuclear power in both developed and developing countries. The United States, where construction had ceased for decades, has now formally certified new reactor designs. In Europe (with the notable exception of France), where nuclear power development has been in a holding pattern for almost two decades, nuclear energy has been the subject of continuous political debate and is now a key element in the European Union's climate-change policy. After an intense debate, Finland's parliament voted in 2002 to approve building a fifth nuclear power plant—the first such decision to build a new nuclear plant in Western Europe for over a decade. A new White Paper on Nuclear Power put nuclear energy at the core of the UK government's energy policy, and the Government's support for new nuclear build was confirmed in January 2008. In May 2008, two decades after a public referendum resoundingly banned nuclear power and deactivated the country's reactors, Italy announced plans to resume building nuclear plants within five years. And in February 2009, Sweden announced plans to overturn a near 30-year ban on new nuclear plant construction. Debates on new nuclear build are underway in Germany, Belgium, the Netherlands and Hungary.

More than 40 developing countries, ranging from the Gulf to Latin America, have recently approached United Nations officials to express interest in starting nuclear power programs (Reuters, 2008). In contrast to North America and most of Western Europe, nuclear power capacity in Asia has been growing significantly. A number of countries in East and South Asia are planning and building new reactors—21 are under construction and there are plans to add 150 more. China, Japan, South Korea and India expected to experience the strongest growth in the region (WNA, 2008a). Indonesia, Vietnam, Thailand, the Philippines and Malaysia are also expressing strong interest in nuclear power (Symon, 2008). In late 2007, Egypt announced that it would build several nuclear power plants to meet rising energy demands (Fleishman, 2007). In June 2008, the South African Cabinet approved an ambitious nuclear energy policy contemplating the installation of 20 GW of nuclear power. There are also ambitious plans to expand nuclear power in Latin America. In September 2008, Brazil's top energy official announced the country's intention to set up 50–60 nuclear power plants in the coming half century (Associated Press, 2008). Argentina is planning to double its existing nuclear capacity and Mexico may add eight more reactors by 2025. Chile, Venezuela and Uruguay are expressing strong interest in nuclear energy (Squassoni, 2009).

This paper describes the current status and future plans for expansion of nuclear power, the advances in nuclear reactor

* Corresponding author. Tel.: +12024739345.
E-mail address: ikessides@worldbank.org (I. Kessides).
[1] Lead Economist, Development Research Group, The World Bank. The findings, interpretations, and conclusions are the authors' own and should not be attributed to the World Bank, its Executive Board of Directors, or any of its member countries.

0301-4215/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2009.07.052

technology, and their impacts on the associated risks and performance of nuclear power. Developments in the United States are given some prominence because nuclear technology originated there and has expanded, in absolute terms, more than in any other country. In addition, the United States has developed a nuclear regulation and supervision system which is arguably the world's most elaborate and demanding. Thus, whatever happens in the United States is a bellwether of developments elsewhere. This is not to minimize accomplishments and future potential in other countries, some of which have built and operated nuclear plants and are at the forefront of industry developments. But the United States, merely by its size, is bound to have an overwhelming influence on future developments. Similarly, US policy initiatives are closely watched and often used as a springboard for action in other parts of the world.

2. A renaissance in nuclear power—why now?

Several factors seem to be driving the resurgence of interest in nuclear power:

- A global desire to diversify fuel sources, reduce dependence on fossil fuel imports, and develop immunity to power disruptions;
- A desire to mitigate volatile fuel costs, given the low dependence of the price of nuclear-produced kilowatt-hours on the price of uranium;
- The need to mitigate climate change by reducing greenhouse gas emissions—specifically, carbon dioxide;
- A desire to decrease air pollution, by taking advantage of the virtual absence of air pollutants from nuclear plants; and
- A way to prepare the transition towards a hydrogen economy.

2.1. Energy security

Dependence on energy imports carries a large risk of disrupted power supplies. Whether such disruption is caused by political events such as the oil embargo of 1973, physical events such as severe weather phenomena, or commercial events such as price disputes, the importing country will have to rely on its fuel reserves to avoid large negative economic impacts.[2] For this reason the International Energy Agency (IEA), the energy arm of the Organization for Economic Co-operation and Development (OECD), has developed plans for coping with such disruptions and requires its members to maintain minimum fuel reserves. In June 2009, the agency estimated that its 30 members had an average of 63 days of oil stocks—the four-to-five-year average cover being 57 days (Reuters, 2009).

For many countries, a large percentage of the fuel needed for their economies may be at sea (or in pipelines traversing politically unstable regions) at any given time, with all the vulnerabilities that this entails. Nuclear fuel may also have to be imported and transported. However, because of the high energy density of nuclear fuel, it is possible for countries to stockpile sufficient imported uranium to operate their nuclear supply systems for many years on the once-through fuel cycle and thus weather any realistic supply interruption. This is a major reason why France and Japan, for example, have tenaciously pursued nuclear power. Other energy resources, such as coal, could also be stockpiled, but uranium has significant advantages: the cost is low (about one-tenth that of coal for equivalent energy); storage is easy (more than four orders of magnitude less mass than the mass of coal for equivalent energy); and uranium, unlike coal, will not degrade in storage (Lidsky and Miller, 1998).

2.2. Avoidance of fossil fuel price volatility

The costs of electricity generation plants consist of three major components: capital or construction costs (those incurred during the planning, preparation and construction of a new power station); operations and maintenance (relating to the management and upkeep of a power station—labor, insurance, security, spares, planned maintenance, and corporate overhead costs); and fuel costs (reflecting the cost of fuel for the power station). Nuclear power also includes a fourth major component: back-end costs—(those related to the decommissioning of the plant at the end of its operating life and the long-term management and disposal of radioactive waste). While annual capital charges are fixed (assuming a fixed interest rate), and operation and maintenance costs should vary little unless major improvements are needed, fuel costs can create major electricity cost volatility. For nuclear power, construction accounts for most of the costs, whereas for gas-fired generation fuel is the largest component.[3] Because of the small weight of fuel cost in the overall cost of nuclear generation, nuclear plants are much more immune to fuel cost volatility relative to gas-fired stations. A doubling in the price of uranium would cause only a 5–6 percent increase in the total cost of generation; while a similar increase in the price of natural gas would lead to a 65 percent increase in gas-fired costs (Fig. 1).[4]

2.3. Global climate change

In 1990 a major environmental concern emerged—the potential for climate change due to rising greenhouse gas (GHG) emissions that trap heat from the sun. That same year, the United Nations Framework Convention for Climate Change was convened and signed in Rio de Janeiro. To implement the convention, the Kyoto Protocol was then negotiated, signed, and ratified by many countries. Although the United States—until recently, the world's largest emitter of greenhouse gases (superceded by China in 2008)—withdrew its signature in 2001, the protocol was eventually ratified by the required number of countries and went into effect in 2005.

The estimated changes in the global climate have led to dramatic predictions of impacts such as accelerated melting of polar ice caps, rising sea levels, reduced availability of freshwater, redistributed agricultural patterns, more extreme weather conditions, and more rapid spread of disease and loss of biodiversity. Stern (2007) estimates that the economic impacts of global warming could reduce global GDP by as much as 25 percent, while greenhouse gas mitigation would cost about 1 percent of global GDP. Obviously, such predictions involve considerable uncertainty.

Like renewable energy sources (hydro, wind, solar, biomass, and geothermal), nuclear power is a low-GHG emitting technology. Indeed, GHG emissions from nuclear and renewable

[2] The publicly articulated rationale for the substantial nuclear power build announced by Brazil was that the political turmoil going on in Bolivia had necessitated measures to end Brazil's dependence on that country for the supply of natural gas 〈http://www.india-server.com/news/brazil-to-build-60-nuclear-powerplants-3712.html〉.

[3] The total fuel costs of a nuclear power plant are typically about a third of those for a coal-fired plant and between a quarter and a fifth of those for a gas combined-cycle plant.

[4] We refer here to the cost of U_3O_8 produced at the uranium mine from ore, which is commonly called "yellowcake". The total cost of nuclear fuel is about 2.5 times the cost of uranium yellowcake.