Article 1: Introduction

The future of nuclear power over the next few decades is murky. In the United States and other industrialized countries, a looming question is what will happen when the current nuclear power plants are retired. Of the 99 currently functioning U.S. nuclear power plants, all but four have been operating for a quarter century or more; the nuclear plants of France and Japan are only about a decade younger. Will these be replaced by new nuclear plants, or have new nuclear plants become too costly in these countries? Could the cost barrier be overcome by a new generation of nuclear plants? In China and some other industrializing countries, a central question is how much nuclear power the country will build. Today, nuclear power provides about 10 percent of the world's commercial electricity. This percentage has been falling; its historic maximum of 17.6 percent was in 1996. Some scenarios for the future mix of energy sources show a continuation of the current steady decline of global nuclear power, and some show an expansion, usually driven by rapid uptake in the developing world.

Two scenarios where nuclear power continues to grow, but that nonetheless are very different from each other, are presented in the International Energy Agency's *World Energy Outlook 2014*. The "Current Policies" scenario projects that by 2040 global production of nuclear electricity will have risen by 60 percent relative to 2012, but nuclear power's share of total electricity will have fallen to 9 percent. By contrast, the "450 Scenario" shows in 2040 an expansion in production by 160 percent and a growth of market share to 18 percent, driven by a seven-fold expansion of nuclear power, relative to 2012, in the developing world. As the appearance of "450" in its name indicates, the latter scenario involves a decrease in carbon dioxide emissions with the aim of stabilizing the concentration of carbon dioxide in the atmosphere at 450 parts per million in 2100, only 50 parts per million higher than today. Global carbon dioxide emissions in this low-carbon scenario fall from 32 billion tons in 2012 to 19 billion tons by 2040, whereas emissions rise to 46 billion tons in 2040 in the "Current Policies" scenario. An increasing role for nuclear power often appears in low-carbon scenarios, because nuclear fission produces no carbon dioxide, and fossil fuel emissions associated with nuclear power are limited to those associated with reactor construction and auxiliary functions like mining and enriching uranium. However, some low-carbon scenarios achieve their target while phasing out nuclear power, relying on other low-carbon energy strategies – notably, renewable energy, fossil fuel use without carbon dioxide emissions ("carbon dioxide capture and storage"), and energy demand reduction.

Alongside these questions about quantity and share of nuclear electricity are questions about reactor size and type. Two reactor types—the pressurized- and boiling-water reactors—have been the primary choice for the current global nuclear power fleet, constituting over 80 percent of all operating reactors. Their typical power capacity (the rate at which they can produce electricity) is approximately 1,000 megawatts, which is also roughly the size of most modern coal power plants, and global capacity is equivalent to 350 of these plants. Both of the dominant types are called "light-water reactors," using ordinary (light) water for removing the heat produced in the reactor and uranium for fuel. Alternatives have long been considered and the many contenders come in varied types and sizes. Until recently, the discussion has been largely about alternatives to the light-water reactor that keep the size at approximately 1,000 megawatts. More recently, the debate over the future of nuclear power has included greater attention to reactor size—specifically whether reactors with a substantially smaller power output are a better choice. This newer debate about size is the subject of this Energy Technology Distillate.

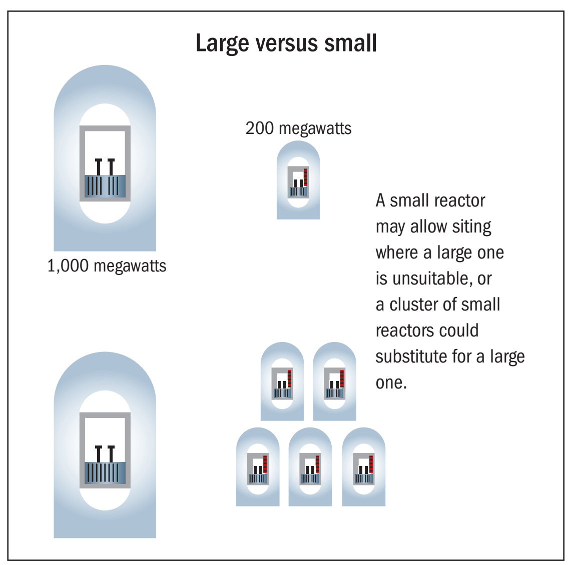

Figure 1.1: Two possible deployments of small modular reactors.

Generally, for a reactor to qualify to be called "small," its capacity must be less than 300 megawatts, that is less than one-third the capacity of the reactors that are common today. Two quite different deployments are being considered: 1) as single reactors in locations where a large reactor is unsuitable and 2) as groups, where several small reactors are intended as an alternative to one large one (see Figure 1.1).

The one-at-a-time deployment strategy could be credible for a country or region with limited total electricity capacity, where a single 1,000-megawatt plant would represent too large a fraction of total national or regional capacity and create systemic risk. A rule of thumb is that, to enhance the stability of an electrical grid, the capacity of no single power plant should be larger than 10 percent of the grid's total capacity. Over 150 countries have a national installed electricity capacity of less than 10,000 megawatts, which would nominally lead them to avoid having any 1,000-megawatt reactors. Moreover, grids are often smaller than country-wide. Of course, a country will be less cautious about building a large reactor if it takes into account its expectations for growth of total domestic capacity and the option of a regional grid that includes several countries. For example, the West African Power Pool involves 14 countries in the region that have come together to establish a regional grid so as to be able to trade electricity. Although none of the individual countries have installed capacities in excess of 6,000 megawatts, with most having under 1,000 megawatts, together their combined installed capacity is close to 12,000 megawatts.

As for groups of small reactors being preferred over single large reactors, this trade-off involves two competing economic principles. The disadvantage of smallness is extra capital cost: five 200-megawatt power plants will generally cost more to build than one 1,000-megawatt plant built in the same way, because of what are called "scale economies." On the other hand, if the numbers of small plants becomes large enough, unit costs can come down by virtue of "economies of serial production." To bring down unit costs, large numbers of small reactors might be built more completely in a factory than large reactors could be, which is why the generic name for the size alternative to today's dominant reactor is the "small modular reactor."

In this distillate, Article 2 outlines a new typology that allows the more than 50 small modular reactor designs to be placed in four broad groups. We then consider small modular reactors from the perspectives of safety (Article 3), linkages to nuclear weapons (Article 4), siting flexibility (Article 5), and economics (Article 6). Article 7 concludes the main text with a brief discussion of policy issues and a table showing some of the small modular reactor designs that are being developed around the world. At the back is an Appendix, "Key Concepts and Vocabulary for Nuclear Energy," which should be helpful background for any reader new to nuclear issues.