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International Status and Prospects for Nuclear Power 2017

Report by the Director General

Summary

- General Conference Resolution GC(50)/RES/13 requested the Secretariat to provide, on a biennial basis, a comprehensive report on the international status and prospects for nuclear power, beginning in 2008. General Conference resolution GC(60)/RES/12, issued in September 2016, requested the Secretariat to continue to publish the *International Status and Prospects for Nuclear Power* report on a four-year basis, starting in 2017, in order to enhance its visibility and make this report an input document for the 2017 International Ministerial Conference on Nuclear Power in the 21st Century. This report responds to resolution GC(60)/RES/12.

International Status and Prospects for Nuclear Power 2017

Report by the Director General

A. Introduction

1. There are 447 operational nuclear power reactors in 30 countries, and 60 are under construction in 15 countries[1]. At the end of 2016, installed nuclear capacity reached 392 gigawatts (electrical) (GW(e)), which is the highest level that has ever been reported. The share of renewable energy continues to expand, but fossil fuels, especially coal, are still the main fuel for energy supply.

2. Many Member States continue to consider nuclear power as a proven, clean, dispatchable and economical technology that is expected to play an increasingly important role in improving energy supply security and mitigating climate change. This was also the conclusion of the Agency's 2013 International Ministerial Conference on Nuclear Power in the 21st Century[2], held in Saint Petersburg, Russian Federation. Since then, two key global developments have shone a fresh light on the potential role of nuclear power in the global energy mix: the adoption of the Sustainable Development Goals and the entry into force of the Paris Agreement on climate change. The Agency's leading role in promoting peaceful uses of nuclear technology, in establishing safety standards and security guidance, and in promoting international cooperation and efforts to strengthen global nuclear safety, security and safeguards continues to be recognized.

3. The Agency's projections for global installed nuclear power capacity in the high case indicate an increase from 2016 levels by 42% in 2030, by 83% in 2040 and by 123% in 2050. The low case projects a dip in capacity of -12% in 2030 and -15% in 2040 before rebounding to present levels in 2050. There are 28 countries interested in introducing nuclear power. Of the 30 countries already operating nuclear power plants (NPPs), 13 are either constructing new ones or actively completing previously suspended construction projects and 16 have plans or proposals for building new reactors.

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[1] As of 1 July 2017. In order to provide a backdrop for the near and longer term prospects for nuclear power, this report includes highlights from the *Nuclear Technology Review 2017* (document GC(61)/INF/4), which presents in detail the status of nuclear power as of 31 December 2016.

[2] This conference followed on from Ministerial Conferences held in Paris, France, in 2005, and Beijing, China, in 2009. The next Ministerial Conference on this topic will be held in Abu Dhabi, United Arab Emirates, from 30 October to 1 November 2017.

B. Nuclear Power Today

B.1. The Evolving Context

4. The national and international policies, market and technological developments that set the stage on which nuclear power competes are continuously shifting. This section highlights important changes since *International Status and Prospects for Nuclear Power 2014* (document GOV/INF/2014/13-GC(58)/INF/6) was issued.

B.1.1. International Initiatives

5. On 4 November 2016, a new global climate treaty, adopted by Parties to the United Nations Framework Convention on Climate Change in December 2015 in Paris, came into force. The Paris Agreement aims to significantly reduce anthropogenic (human-made) greenhouse gas (GHG) emissions in order to limit the increase in the global average temperature from pre-industrial levels to less than 2°C or even 1.5°C subject to further scientific information. Its goals are to be achieved through time by increasing aggregate and individual ambition, through a mandatory cycle of nationally determined contributions: every five years until the global temperature has stabilized, countries must re-evaluate progress made and submit a progressively ambitious climate action plan. Energy-related emissions make up three quarters of global GHG emissions, and within this area, the electricity sector shows the largest growth. Nuclear power, as a low carbon technology, has significant potential to contribute to efforts to address the climate challenge.

6. On 1 January 2016, the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development, adopted at a September 2015 United Nations summit, came into force. Seen as the successors to the Millennium Development Goals (MDGs), the SDGs call upon all countries, poor and rich, to mobilize efforts over the next 15 years to end all forms of poverty, fight inequalities and tackle climate change. This goes hand in hand with strategies that build economic growth and address social needs, including education, health, social protection and job opportunities, while tackling climate change and environmental protection. Whereas energy was not included in the MDGs, it is now fully recognized as a fundamental pillar in its own right, as expressed in SDG 7: "Ensure access to affordable, reliable, sustainable and modern energy for all".

7. The 2°C scenario of the International Energy Agency (IEA) is aimed at avoiding the most damaging consequences of climate change. The IEA's *Tracking the Clean Energy Progress* report for 2017 recommends a large increase in the use of nuclear energy. The report notes that 10 GW(e) of new nuclear generating capacity was added in 2016 — the highest addition since 1990. However, the report highlights that annual capacity additions of 20 GW(e) per year by 2025 are needed to meet the 2°C targets. A major shift of energy investments from fossil fuels towards low carbon technologies was observed in 2015 and 2016. However, although investments in nuclear power generation reached $21 billion in 2015, $221 billion were invested in energy efficiency initiatives and $313 billion in renewables.

8. The World Nuclear Association's (WNA's) vision for the future of electricity generation, called 'Harmony', envisages a diverse mix of low-carbon generating technologies deployed in such a manner that the benefits of each are maximized while the negative impacts are minimized. The WNA has set a target of 25% of global electricity in 2050 to be provided by nuclear energy, which would require roughly 1000 GW(e) of new nuclear capacity to be constructed, depending on other factors such as reactor retirements and electricity demand growth. To meet this target, the global nuclear sector would need a level playing field, harmonized regulatory processes and an effective safety paradigm.

9. In 2015, the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD) launched the Nuclear Innovation 2050 (NI2050) initiative. Its aim is to produce a roadmap of main priority research programmes and infrastructures necessary to support the role that nuclear energy may play in the low-carbon power sector of the future. The work to be undertaken under the NI2050 initiative consists of a survey phase, a roadmapping phase and an implementation phase, and will be completed in 2017.

10. In 2015, an agreement signed between the IAEA and the International Renewable Energy Agency (IRENA) established a framework for cooperation in the area of energy planning, which is aimed at enhancing the effectiveness and impact of relevant capacity building efforts. The agreement identifies several areas of cooperation, including information exchange, sharing of data and methodologies, participation in training events and cooperation on case studies.

B.1.2. Trends in Technology

11. At present, over 17 advanced water cooled reactor designs and technologies have been developed in 7 Member States. These advanced reactor designs are commercially available for immediate and near term deployment, with more than 30 such reactors under construction. These reactor designs share the objective of enhancing safety, operability and reliability while promising better economic competitiveness through technical improvements. The licensability of new designs, the preparedness of the regulatory framework, construction technologies and management, supply chain availability and viable project financing have been among other factors affecting the successful deployment of such advanced reactors.

12. Significant advances have also been made in the design and technology development of small and medium sized or modular reactors (SMRs). This newer generation of modular reactors are designed to generate up to 300 MW(e). Equipped with factory fabricated systems and components, and being transportable as modules to the sites as demand arises, SMRs aim for the economy of serial production with short construction schedules. They offer flexible power generation for a wider range of users and applications, including replacing ageing fossil power plants. With a potential reduced emergency planning zone size and requiring less cooling water, SMRs could be deployed at locations that are not feasible for large NPPs. There are about 50 SMR designs and concepts worldwide, some of which are said to be near-term deployable, and several countries with existing nuclear power programmes as well as newcomer countries are conducting SMR research and development. The three SMR types that are in advanced stages of construction in Argentina (CAREM), China (HTR-PM)[3] and the Russian Federation (KLT40) are scheduled to begin commercial operation between 2018 and 2020. The first commercial fleet of SMRs is expected to operate in the time frame of 2025–2030.

13. For some countries fast reactors provide a vital future option to achieve long term sustainability of nuclear power. In the Russian Federation, the sodium cooled fast breeder reactor BN-800 was connected to the grid at full-power in 2016, while India's Prototype Fast Breeder Reactor is expected to start operation in 2017. Several other countries continue their fast reactor and fuel cycle programmes, though at different paces of development.

14. High temperature gas-cooled reactors (HTGRs) offer a broad variety of non-electric high temperature applications (e.g. petrochemical refineries, thermochemical hydrogen production and other industrial applications), which can have a significant impact on the reduction of carbon dioxide (CO_2) emissions. China, which plans to commission its first HTGR soon, recently signed a cooperation agreement for a joint study on the feasibility of constructing HTGRs in Saudi Arabia.

[3] HTR-PM: High Tempeature Reactor–Pebble-Bed Module.

Poland is considering demonstration of cogeneration on an industrial site with an HTGR, in a project supported by the EU, Japan, the Republic of Korea and the USA, through a joint initiative called PRIME.

B.2. Current Status of Nuclear Power

15. Global nuclear electricity generation in 2016 was 2476 terawatt-hours (TW·h), which is 91 TW·h less than the average for the first decade of the twenty-first century. This drop resulted mainly from decreases due to permanent and temporary shutdowns in Japan, as well as permanent shutdowns in Germany and the USA, which were offset partly by increases in China and other countries.

16. The left panel in Figure 1 shows the geographical distribution of the 447 nuclear power reactors that are in operation in 30 countries around the world. Industrialized countries still account for most commercial use of nuclear power. The situation is very different for plants under construction (the right panel in Figure 1): of the 60 new reactors under construction worldwide, 39 are in the rapidly developing countries of Asia. Since 2000, this region has accounted for 85 of the 105 construction starts and 63 of the 78 new reactors to have been connected to the grid. In 2015 and 2016, 20 new reactors were connected to the grid across the world, the highest number since the 1980s.

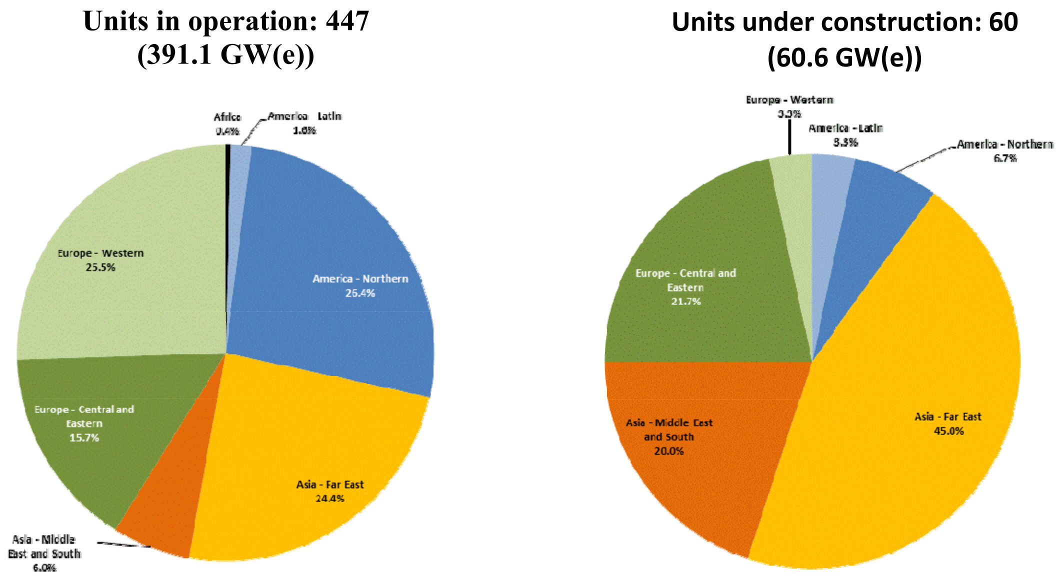

FIG. 1. Global status of operational nuclear power reactors (left) and those under construction (right), as of 1 July 2017. Source: IAEA Power Reactor Information System.

17. The share of nuclear power in total global electricity generation decreased for the tenth year in a row, to almost 11% in 2015. Yet, this still corresponds to nearly a third of the world's low carbon electricity production. The rapid policy-driven expansion of wind, solar and biomass in electricity generation continued, but fossil fuels, especially coal, still remain the main fuel for energy supply (see Figure 2). Although new renewables (which include wind, solar and geothermal power, but not hydropower) have surpassed nuclear power in total installed capacity, their share of actual electricity generation is less than one third of that produced by nuclear power because of their intermittency.

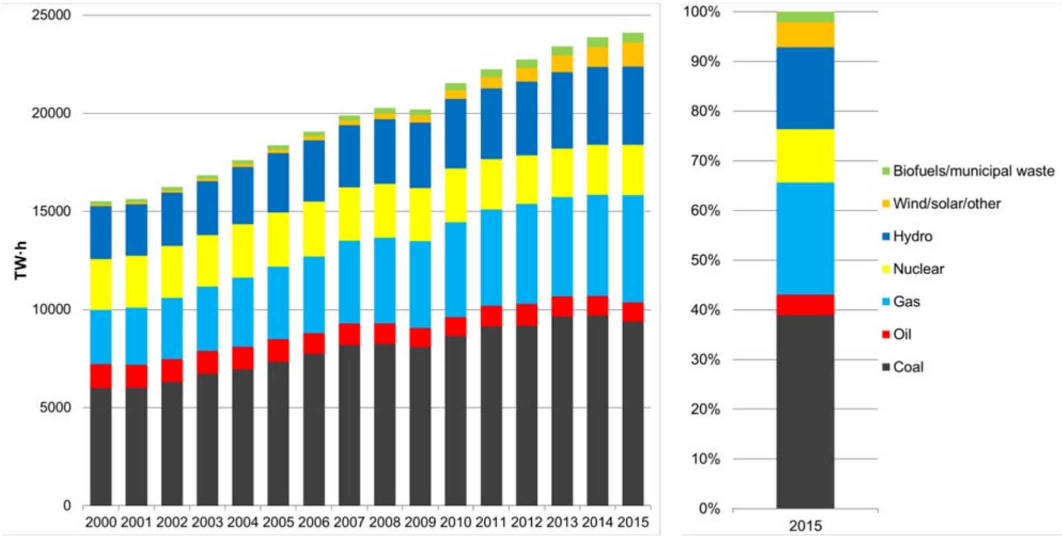

FIG. 2. Global electricity supply by fuel, 2000–2015. Source: Adapted from IEA and BP.

18. Electricity demand in developing countries is approaching that of the industrialized countries and will likely surpass them well before 2020. Unlike in regions with stagnating demand, rapidly growing demand generally encourages the development of all locally available and appropriate electricity generating options, including nuclear power. Figure 3 shows the shift in global electricity generation from OECD to non-OECD countries.

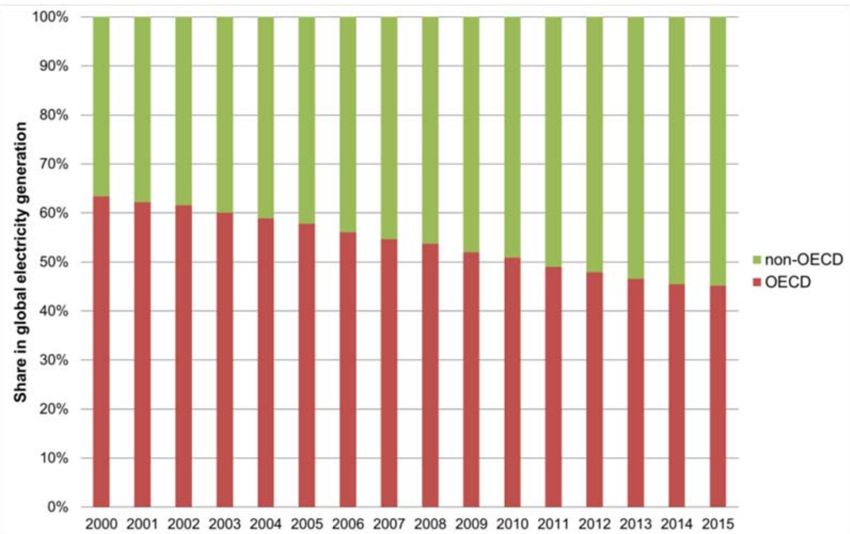

FIG. 3. Share in global electricity generation in OECD and non-OECD countries, 2000–2015. Source: Adapted from IEA and BP.

19. Until recently, nuclear power has weathered the transition from regulated electricity markets to liberalized (competitive) markets remarkably well. Reactors proved to be competitive low-cost generators, largely because their high initial upfront investment costs were fully depreciated and operators had to bear only operating and fuel costs, which were low compared to those for fossil fuelled generation. This cost advantage was the prime reason that utilities sought licence extensions and performed safety upgrades and power uprates. However, in recent years, some owner/operator organizations have announced plans for early shutdown of a number of NPPs with valid operating licences, or those that could reasonably have had their operating licences extended. In many cases, reduced competitiveness has been cited as the main reason for these premature shutdowns: low natural gas prices, particularly in the USA, caused by a rapid expansion of shale gas production, have fundamentally transformed the energy economy.

20. Spent fuel is discharged at a rate of around 7000 tonnes of heavy metal per year. Most of it is stored under wet conditions in at-reactor storage facilities, but the amount of fuel being transferred to dry away-from-reactor storage facilities has substantially increased in recent years and now accounts for around 25% of all stored fuel. The largest inventories of fuel in dry storage are in Canada and the USA. With major facilities operating in France, the UK and the Russian Federation, average reprocessing capacity worldwide is expected to remain unchanged, despite the planned shutdown of two Sellafield reprocessing plants, in the UK, in 2018 and around 2020. Additional reprocessing capacity is planned in China and the Russian Federation, and the Rokkasho plant in Japan is expected to be commissioned in the near future.

21. Like any other industrial facility, an NPP is decommissioned after its operational phase. To date, 162 power reactors have been shut down or are undergoing decommissioning, of which 19 have been decommissioned. More than 150 fuel cycle facilities have been permanently shut down or are undergoing decommissioning and 127 have been fully decommissioned. As safe operating experience has increased, so the operational phase has often been extended.

C. The Prospects for Nuclear Power

C.1. Plans in Countries Considering, Introducing or Expanding Nuclear Power Programmes

22. Table 1 shows the expansion plans[4] in the 30 countries that are currently operating NPPs, of which 13 are either constructing new units or are completing previously suspended construction projects. There are plans or proposals for new reactors in 16 operating countries.

TABLE 1. Positions of countries with operating NPPs.

Category	**Countries**
New unit(s) under construction	Argentina, Brazil, China, Finland, France, India, Japan, Republic of Korea, Pakistan, Russian Federation, Slovakia, Ukraine, USA
New unit(s) under construction with more planned/proposed	China, Finland, India, Japan, Republic of Korea, Russian Federation, Pakistan, USA
No units under construction but with plans/proposals for building new unit(s)	Armenia, Canada, Czech Republic, Hungary, Islamic Republic of Iran, Romania, South Africa, UK
Firm policy not to build new units	Belgium, Spain, Switzerland[5]
Firm policy to close existing units	Germany

[4] Based on statements made by Member States at the 60th regular session of the General Conference in September 2016 and at other public forums, as of July 2017.

[5] About 58.2% of voters in Switzerland backed a ban on new NPPs in a May 2017 referendum. The five plants currently generating 34% of Switzerland's electricity are allowed to operate as long as they are deemed safe.

23. Currently, 28 Member States[6] are considering, planning or starting nuclear power programmes, but have not yet connected a first NPP to the grid. Table 2 divides them into five groups, based on their infrastructure development according to the Agency's Milestones approach[7]. An additional 20 (the last row in Table 2) have expressed interest in nuclear power, participate in some nuclear infrastructure related Agency activities, and are involved in Agency-supported technical cooperation projects on energy planning.

24. Since the last report in 2014, Belarus and the United Arab Emirates (UAE) have progressed in building their first NPPs and four countries have decided to postpone or scrap their plans for nuclear power. Several countries in Africa have moved forward with their plans after hosting Integrated Nuclear Infrastructure Review (INIR) missions conducted by the Agency. Some, such as Bangladesh and Turkey, have ordered their first NPP and have initiated the site and construction licence processes. Others, such as Egypt and Jordan, are in the contractual negotiation phase, or are about to take a knowledgeable decision or prepare for contracting, such as Ghana, Kenya, Nigeria, Poland, Saudi Arabia and the Sudan, although national decisions reflecting broad political support are still pending in some cases.

TABLE 2. Positions of countries without operating NPPs.

Country Status	**Countries**
First NPP construction started	2
First NPP ordered	2
Decision made, preparing infrastructure	5
Active preparation with no final decision	7
Considering nuclear power programme	12
Expressed interest in nuclear power	20

25. All 'newcomer' countries — those that are introducing nuclear power for the first time — have adopted the Agency's Milestones approach and are carefully following the steps required for each of the 19 infrastructure issues. As a result, there has been growing demand among Member States for Agency support, in particular for reviewing nuclear power infrastructures in a systematic and integrated way against Agency safety standards and other guidance in order to identify gaps and to develop appropriate plans to remedy these gaps. One of the review services offered by the Agency that nuclear newcomers request most frequently is the INIR service, launched in 2009. To date, 22 such missions have helped 16 Member States assess their own status of nuclear infrastructure development, and benefit from recommendations by international experts on how to make further improvements. These Member States have thus been enabled to adopt a holistic and consistent approach to considering, developing and reviewing their nuclear power infrastructures, with close attention being

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[6] Based on ongoing Agency assistance projects for nuclear power infrastructure development, as well as statements made by Member States at the 60th regular session of the General Conference in September 2016 and at other public forums, as of July 2017.

[7] This refers to the approach outlined in *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1).

paid to safety, security, safeguards and sustainability issues. South Africa, as an operating country, also recognized the value of inviting an INIR mission ahead of expansion plans. The Agency's support has also taken other forms, including the development of documents on financial risk management for new NPP projects.

26. The UAE is expected to commission its first nuclear reactor in 2018, with three other units to follow by 2020. Belarus, another advanced Phase 3 country, will follow in 2019 and 2020, commissioning its first two units. The Agency is offering for the first time to conduct a Phase 3 INIR mission to review preparedness to commission the first NPP. Undertaken at the request of a Member State, INIR missions provide the government with an overall integrated view, including a summary of the findings of any issue-specific missions or reviews that were undertaken prior to the INIR mission. The Phase 3 INIR missions thus provide a final assessment on the readiness of the overall infrastructure for commissioning and operations.

27. Figure 4 provides a global overview of potential capacity additions by Member States embarking for the first time on nuclear power programmes by 2030. It compares announced capacity additions with those that might be expected if a conservative view were taken of Member States' plans.

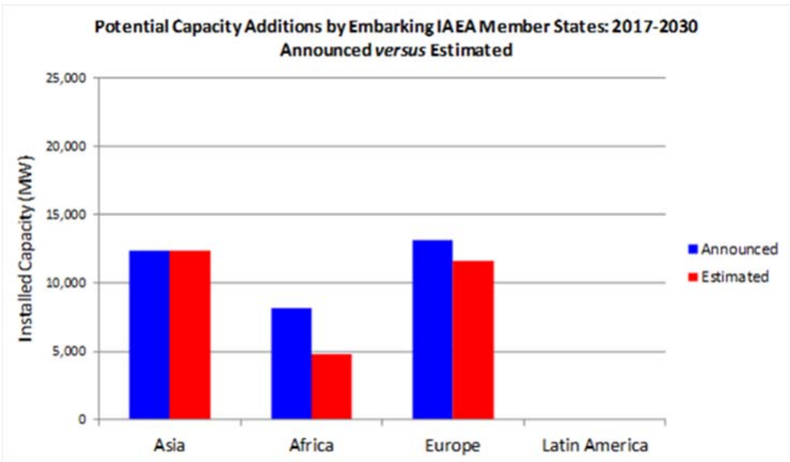

FIG. 4. Global overview of potential capacity additions in embarking countries by 2030.

C.2. Projections and Interpretations of Future Growth

28. The Agency publishes[8] annually projections for the world's nuclear power generating capacity: a low projection and a high projection. Renowned experts from around the world participate in this exercise to consider all the operating reactors, possible licence renewals, planned shutdowns and plausible construction projects foreseen for the next several decades. They develop estimates of future nuclear generating capacity on a project-by-project basis by assessing the plausibility of each in the light of the assumptions on which the low and high projections are based. This section briefly presents the results of this 'bottom-up' exercise for both projections and then interprets them taking into account the observations from the previous sections of this report.

[8] *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050* (Reference Data Series No. 1), 2017 edition, to be published in September 2017.

C.2.1. The Low Projection

29. The low projection assumes that current trends will continue with few changes in policies affecting nuclear power. It does not assume that all national targets for nuclear power will be achieved. It is a ‘conservative but plausible’ projection.

30. According to the 2017 low projection, global nuclear power capacity will decrease from 392 GW(e) at the end of 2016 to 345 GW(e) by 2030, and will decrease further to 332 GW(e) by 2040, before recovering to present levels by 2050[9]. The global totals reflect distinctly different regional developments. Significant decline is expected in North America and in the region including northern, western and southern Europe, with only slight increases in Africa and western Asia. In contrast, significant growth is projected in the region including central and eastern Asia, with nuclear power capacity there expected to undergo an increase of 43% by 2050.

31. More than half of the 447 reactors currently in operation are over 30 years old. The low projections through to 2050 appear to show no net growth in installed capacity; however, that does not mean there is no new construction. In fact, even in the low case, some 320 GW(e) of new nuclear power capacity will be installed by 2050, making up for the loss caused by retiring reactors, albeit not necessarily in the same regions.

C.2.2. The High Projection

32. The high case assumes that current rates of economic and electricity demand growth will continue, with particularly high growth in the Far East. Nuclear power would also be accepted in many countries as a cost-effective climate change mitigation option.[10]

33. According to the high projection, global nuclear power capacity reaches 554 GW(e) by 2030, 717 GW(e) by 2040 and 874 GW(e) by 2050. All regions contribute to the expansion, with the largest growth occurring in the region including central and eastern Asia, where capacity more than doubles by 2030, increases 2.9 times by 2040, and increases about 3.5 times by 2050, compared to current levels. Capacity in the North America region decreases slightly by 2050, and in the region including northern, western and southern Europe initially dips but recovers to reach 120 GW(e) by 2050, slightly rising above the current level of 113 GW(e).

34. Despite improvements in electrical efficiency, global electricity demand grows, mainly driven by emerging economies, several of which will have embarked on new nuclear power programmes or expanded existing programmes. These economies can particularly benefit from ‘electro-mobility’, i.e. shifting away from the use of fossil fuels in transportation, thus avoiding air pollution and carbon emissions.

C.2.3. Comparing the High and Low Projections

35. Since 2010, the Agency’s annual projections of total nuclear power generating capacity have progressively declined. Nevertheless, the long term potential of nuclear power remains high. Figure 5 compares 2016 capacities to the wide range of future projections, highlighting the high degree of substantial uncertainty in nuclear power’s future. The current reactor deployment plans reported in Section C.1 lie within the range of the projections. In the low projection, nuclear power’s share of global electricity generation declines from the current level of about 11% to 7.8% in 2030, to 6.2% in

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[9] The projections include all available capacity that is classified by Member States as ‘operational’, irrespective of whether it is online or temporarily shut down. In 2016, much of the Japanese capacity was temporarily shut down.

[10] See *Climate Change and Nuclear Power 2016* (IAEA, Vienna, 2016).

2040, and to 6% by 2050. However there remains absolute, though modest, growth in global nuclear electricity generation. In contrast, nuclear electricity generation in Asia is increasing at greater rates, matching overall electricity growth even in the low case.

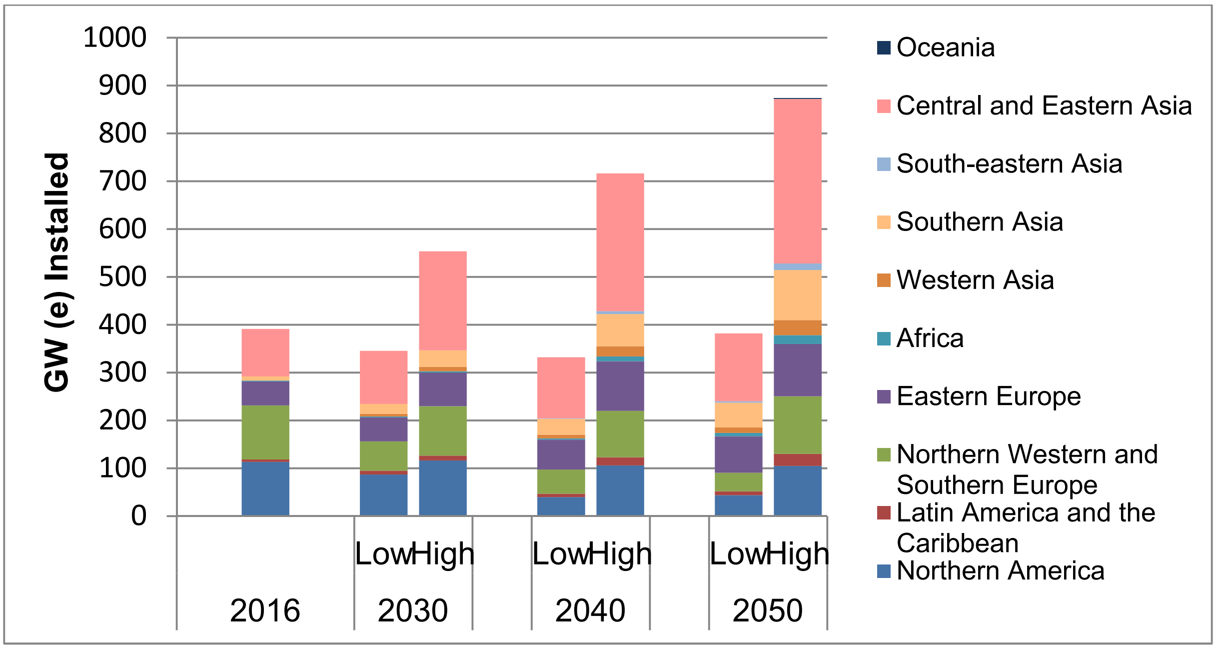

FIG. 5 The Agency's 2017 low and high projections by region of installed nuclear capacity GW(e).

36. In the high projection, the estimated share of nuclear power in the total electricity supply increases from 11% currently to 12.4% in 2030, to 13.4% in 2040, and to 13.7% in 2050. This projected growth of the nuclear share is driven by energy growth in developing countries. Globally, the high projection reflects that 30–35 new reactors are expected to be connected to the grid every year starting around 2025. This rate of connections was last seen in 1984, when 33 new reactors were connected to the grid. Currently, global manufacturing capacity (primarily heavy forgings) is estimated at 30–34 reactors per year. The greatest limitations are not in production but in securing political support, monetizing nuclear power's benefits compared to other energy systems (such as low carbon emissions, energy security, job creation), and better communicating the benefits and risks to investors and the public. In short, 33 grid connections by 2025 would require immediate action today.

37. As of 1 January 2015, the annual world uranium production of 55 975 tonnes of uranium provided about 99% of annual world reactor requirements, with the remainder supplied by previously mined uranium. The uranium resource base is considered to be more than adequate to meet projected demand requirements until 2030. However, in order to meet high case demand, timely investments will be necessary to enable these resources to be brought into production and be ready for use in nuclear fuel production.

D. Influential Factors

38. This section highlights some of the factors that might be important in determining whether future developments will be closer to the low or the high projection.

D.1. Safety

39. The safety performance of nuclear installations is crucial to the future of nuclear power, as a strong safety record is essential for its public acceptance.

40. Since the Fukushima Daiichi accident and the adoption of the IAEA Action Plan on Nuclear Safety in 2011, the Agency, its Member States and relevant organizations have been implementing measures to strengthen nuclear safety worldwide. There was a particular focus on the safety of NPPs during extreme natural events, and on related fuel cycle, radioactive waste management and radiation safety issues. Progress made in improving global nuclear safety included more effective defence in depth, strengthened emergency preparedness and response capabilities, and enhanced measures for the protection of people and the environment from ionizing radiation.

41. The Agency has been revising its Safety Requirements to take account of the lessons learned from the Fukushima Daiichi accident. Member State requests for the Agency's peer review and advisory services continued to increase, as did the requests for assistance with developing their programmes for leadership and management for safety, and with capacity building.

42. Procurement related activities have a key impact on safety. There have been numerous activities within the nuclear industry in recent years addressing issues related to counterfeit, fraudulent and suspect items. Procurement engineering and an efficient supply chain programme with high quality control and assurance processes will support the safe and economic operation of nuclear facilities.

D.2. Funding and Financing

43. There are funding needs that arise during the various phases of an embarking or expanding country's nuclear power programme, such as for establishing and maintaining a national regulatory body, and for establishing funding mechanisms to meet the 'back-end liabilities' of decommissioning and waste management. This is primarily a government role. The Agency has provided support to a number of Member States in this area, including through national workshops conducted in Belarus, Jordan and Turkey.

44. The financing of nuclear projects is challenging, given the highly capital intensive nature of such projects, their resulting sensitivity to interest rates and construction durations, and the nature of the uncertainties. A variety of potential financing models have been developed to address some of these uncertainties, particularly those market risks to which project developers — and providers of finance — may be exposed to during the operating phase of a plant's life cycle. These risks, which may lead to a plant being unable to sell the power it produces at an adequate price, may be perceived as particularly severe in liberalized electricity markets. Mitigation of such risks may be achieved through arrangements — potentially backed by the government of the country hosting the plant — to buy some or all of the power produced by a plant at a guaranteed fixed price. Such arrangements have been central to developing projects such as Akkuyu (Turkey), Hinkley Point C (United Kingdom), and Olkiluoto and Hanhikivi (Finland).

45. Although such arrangements can help in securing financing for projects by mitigating market risks, they are of limited use in addressing the risks to which nuclear projects are perceived to be vulnerable at earlier stages of their life cycle — those of construction delays and associated cost overruns. In order to maximize the share of relatively low-cost loan financing in a project's financing structure, it is important that the project be 'de-risked' from the perspective of lenders. This can be accomplished in a number of ways, for example by the host government providing direct sovereign guarantees to lenders, or by nuclear steam supply system vendors agreeing to take an equity stake in the project. The latter happened in the Barakah project in the UAE where the Korea Electric Power

Corporation has taken an 18% equity stake in the Barakah One Company, as well as in the Hanhikivi project in Finland where the State Atomic Energy Corporation "Rosatom" took a 34% share.

D.3. Electricity Markets and Nuclear Policies

46. Key developments in the global power markets since 2014 include the decline of gas prices, the rapid deployment of large amounts of renewable energy, the shifting of electricity demand from OECD to non-OECD countries, particularly in Asia, and the absence of a meaningful CO_2 price signal.

47. The Paris Agreement (see section B.1.1) can have a positive influence on nuclear power development if nuclear power's potential as a low-carbon energy source is more widely recognized. In some countries, the climate change issue is an incentive to support continued operation of NPPs that would otherwise be shut down for economic reasons, or part of the justification for having a new build programme. In the long term, the quinquennial (or five-year) updates of countries' nationally determined contributions under the Paris Agreement and the value it places on innovation could be another positive influence, as advanced reactor designs would further improve both safety and radioactive waste management. Over time the advanced technologies may become commercially available for consideration as part of a low-carbon energy mix. However, maintaining an operating fleet is still necessary in order to bridge the gap between existing and next-generation technologies.

48. The IEA projections suggest that achieving the Paris Agreement objectives (see section B.1.1) would require at least a doubling of current nuclear power capacity levels by 2050. Electricity market incentives that promote all types of low carbon solutions, including nuclear power, will play a fundamental role in providing financing certainty for investment in nuclear power and thus ensuring its timely deployment for climate change mitigation. In parallel, the advantages of security of supply, reliability and predictability that nuclear power offers need to be recognized. This is all the more urgent in an electricity environment that has become ever more volatile due to the introduction of large amounts of variable renewable technologies such as wind and solar photovoltaics. Recent policy examples serve to emphasize the role of electricity markets in nuclear power development: in the UK, the contract for difference mechanism guarantees the price for electricity; in the USA, New York State's Clean Energy Standard includes a zero-emission credit to value the non-emitting attribute of nuclear energy; in Mexico, annual auctions are held to achieve a 35% target for low-carbon energy generation (including nuclear power) by 2024. In the absence of effective actions to support long term financing arrangements, the pace for nuclear power development might be reduced and the climate change mitigation be jeopardized.

49. As energy is now a fundamental pillar on its own within the SDGs (see section B.1.1), the benefit of nuclear power in sustainable development can become more explicit. The place of nuclear power in sustainability issues has generated substantial controversy so far because of its trade-offs between low carbon electricity and concerns related to the risks of accidents as well as environmental and human health issues associated with radioactive waste management. The Agency has reviewed the characteristics of nuclear power in comparison with alternative sources of electricity supply and in connection with the SDGs relating to the economic, social and environmental pillars of sustainability. In the light of a wide range of indicators, nuclear power can be seen as a reliable source of power that can play a role in energy supply diversification and foster a more resilient sustainable power supply.

D.4. Innovation: Advanced Reactors and Fuel Cycles

50. There is renewed interest in advanced, alternative fuel designs that would improve performance and be more resistant to fuel failure and hydrogen production under accident conditions. Some of these new fuel designs could be deployed with existing reactors and those under construction. There are also several advanced fuel designs under development for new reactor systems and their fuel cycles.

51. Fast reactors will not play a decisive role before 2050 but could become important thereafter, especially when sustainability considerations call for waste burden minimization (both in terms of volume and longevity) and for the effective utilization of uranium resources.

52. The use of nuclear energy for cogeneration of heat and power, as well as for the recovery of rejected heat, allows for potential penetration into the market for non-electric applications. This would result in an increase of the operating efficiency accompanied by economic advantages. As an alternative to conventional fossil based systems serving the heat sector, nuclear cogeneration plants can help limit CO_2 emissions. Cogeneration can also facilitate variable electrical output to support intermittent renewables by switching between electricity generation and other applications. Thus, nuclear power can contribute to the total energy market, increasing its impact beyond electricity generation.

53. Low temperature applications have been successfully demonstrated in several Member States with more than 750 reactor years of operating experience. In these cases hot water and steam are generated for applications with operating temperatures below 200°C (e.g. paper mills, district heating and desalination). In the future, it will be possible to use advanced non-water cooled NPPs for high temperature applications. The commissioning of the first HTGR in China could pave the way for a more extensive deployment of HTGRs. Such reactors can also accommodate a broader variety of non-electric high temperature applications.

54. Offering important advantages for countries with small electric grids, less developed infrastructure and limited investment capabilities, and for specialized applications such as deployment in remote areas, process heat and desalination, the commercial deployment of SMRs could also have an impact on the future of nuclear power (see Section B.1.2).

D.5. Waste Management

55. Demonstrated progress in the development and implementation of high level waste (HLW) repositories will have a profound impact on the political and public acceptance of nuclear power. Countries with clearly defined waste management policies in place and that have achieved visible progress towards operational HLW repositories are among those with the highest levels of public acceptance.

56. The safe and effective disposal of the vast majority of radioactive waste continues to be accomplished around the world. For the remaining, much smaller, volumes of HLW and spent nuclear fuel, good progress towards operation of disposal facilities continues in several countries. In November 2015, the first construction licence for a deep geological disposal facility for spent nuclear fuel was granted for the Onkalo facility in Finland, and construction started in December 2016. In June 2016, the Swedish Radiation Safety Authority endorsed the licence application for the spent fuel deep geological repository at Forsmark. In France, the licence application for a deep geological disposal facility, called Cigéo, for intermediate level and high level radioactive waste, is under preparation.

57. Discussions among some interested Member States on multinational options for the safe disposal of spent nuclear fuel and high level radioactive waste have continued. Whilst these have not yet resulted in commitments to proceed with the construction of specific facilities, the willingness to engage openly on this topic indicates that the potential benefits may be substantial.

58. Decommissioning provides a basis to prepare for the future, allowing the site to be reused for construction of a future power station or indeed for industrial or other uses not involving the use of radioactive materials. With decommissioning efforts and technology now reaching industrial maturity, mastering the end of life of NPPs is also an influential factor for the future of nuclear power.

D.6. Capacity Building

59. Acquiring and retaining skilled personnel to ensure a competent workforce for all phases of the nuclear facility life cycle are among the biggest challenges for the nuclear community. A particular challenge for nuclear new build projects is the loss of expertise and human capital, because such projects are few and often take place many years after the previous one (with the exception of China, Japan, the Republic of Korea and the Russian Federation). Innovative approaches, such as digital and blended learning, are put into practice to make nuclear training, education and capacity building more easily accessible to new generations of the nuclear workforce in both operating and newcomer countries.

60. The Agency continues to connect communities of practice under networks and regional arrangements. Its Nuclear Knowledge Management and Nuclear Energy Management Schools have expanded, with new Schools held in the Russian Federation and South Africa in 2016, in addition to the ones regularly held in Italy (jointly with the International Centre for Theoretical Physics in Trieste), Japan, and the UAE.

61. The use of, and access to, research reactors have continuously proved to be an asset in terms of providing a practical component in the training of students and nuclear professionals. In response to Member States' requests, the Agency has recently developed different schemes and opportunities for nuclear capacity building and preservation based on research reactors, including hands-on training courses, distance learning tools such as the Agency's Internet Reactor Laboratory project, and a mutual cooperative scheme known as the IAEA-designated International Centre based on Research Reactor (ICERR) initiative.

62. E-learning modules developed for specific audiences, such as nuclear power newcomers and radioactive waste management, decommissioning and environmental remediation practitioners, are in extensive use.

D.7. Public Acceptance

63. Public acceptance is a key factor for the future of nuclear power. It largely depends on public perception of the benefits and risks associated with nuclear power, but also of the benefits and risks of non-nuclear alternatives. In particular, concerns about radiation risks, waste management, safety and proliferation remain the areas that most influence public acceptance.

64. Stakeholder involvement in nuclear policy formulation and investment decisions, especially with potential safety implications, has become a central feature in the successful and safe deployment of nuclear power. It is indispensable for the development of a national position in newcomer countries, and for the siting of new nuclear construction projects and HLW repositories. It also helps build and maintain trust in regulatory competence and efficiency.

65. Timely communication and public involvement in nuclear power projects contribute to better understanding, and are more likely to lead to informed consent by stakeholders. Transparent and participative processes at all stages of a nuclear power programme are crucial for fair and consistent decision-making, as well as for harnessing the full potential of the nuclear sector.