Global Status of Commercial Nuclear Power

Vojin Joksimovich, PhD
ANS San Diego Chapter
November 15, 2017

Content

- N Drivers: Power, Climate Change & Electric Cars
- Carbon Footprints: Electricity Generation Sources
- Nuclear Electricity Generation (NEG) Projections & 2017 World Status, Roadblocks
- Roadblocks: Severe Accidents, Post Fukushima Japan
- Nova Publishers Book: Vojin's Fukushima Chapter
- Roadblocks: Cost Overruns
- US Overview Including Westinghouse Bankruptcy
- Nuclear Leaders Snapshots: Russia, China, France
- Secondary Leaders Snapshots: UK, India, S. Korea
- Some Conclusions

Climate Change & Electric Cars

- 2015 Paris Accords (COP-21), 195 countries pledge, 2 degree C ceiling, N power ~ zero carbon emitter
- 2016: CO2 concentrations surged to records: 145% of pre-industrial level, US emissions plummeted
- 2017: Trump withdrew from COP-21-not good deal for US; COP-21 will survive without US
- EPA: rulemaking to repeal Obama's 2015 Clean Power Plan (CPP): 32% cut in CO2 emissions from 2005 levels by 2030, natural gas &, solar vs. coal
- UN Report: Pledges to achieve only 1/3 reduction
- China: 1/3 global car sales, to replace combustion-engine cars; targets: India (2030), UK/France (2040), CA to follow?; 2030 EU 30% cut in auto emissions

Carbon Footprints: Electricity Sources

- Total Amount of CO2 plus other greenhouse gases emitted over full fuel cycle from extraction of raw materials through decommissioning in gCO2/kWh:
- Coal 823-1075
- Oil 650
- Natural Gas 411-440
- Biomass 25-237
- Photovoltaics 35-58
- Marine 25-50
- Hydroelectric 3-10
- Wind 4.5-5
- Nuclear 3.5-5 (40% from mining)

Nuclear Generation Projections vs. 2017 Status

- WNA: Harmony Model (2 degree C, 1980s build rate): NG 25% global electricity, 1000GW new builds by 2050; 10GW/yr now (20 online in 2015/2016), 25GW in 2021-25, 33GW from 2026 onward
- Komarov-2018 WNA chair; advocates more ambitious NG capacity target, 1000GW modest
- 444 plants operating, 390.6 GW, 31 countries, 11.5% world electricity; averting release of 2.5bn CO2/yr
- Generation II (~85%); Gen III (~10%), Gen III+: Russian Novovoronezh II/1, Korean Shin-Kori 4
- NN 96 plants forthcoming, 98.3GW; WNA 61 under way: 2/3 in Asia, half in China; 57 planned/proposed
- Roadblocks (barriers): Severe Nuclear Accidents, Cost Overruns; WNA: Level playing field in markets, Harmonized regulatory process, Safety paradigm

Roadblocks: Severe Nuclear Accidents

- Three in 60-year history: US 1979 Three Mile Island (TMI-2), USSR 1986 Chernobyl, Japan 2011 Fukushima Daiichi (FD)
- TMI-2 B&W PWR: 45% core melt, insignificant radioactive release, $35bn US backfits, no new US orders in ~30 yrs
- Chernobyl 4 Soviet RMBK-1000: largest radioactive release in history, out of 600 first-responders 134 received radiation doses of >4000mSv, 28 died in 3 months; N phase-out in Italy, EU demanded & paid for closure of Chernobyl 1-3, Ignalina in Lithuania, even 440 VVER/V230s in Bulgaria and Slovakia
- FD: 4 BWRs: triple meltdown, triple hydrogen explosions, large release of radioactivity <1/10 Chernobyl, no observable health effects; crippled Japanese N program; Germany: 8 plant instant shutdowns, 2022 phase-out, 2017 US coal exports up 94%; no N restart in Italy, gradual phase-outs in Belgium, Switzerland; later phaseouts in Taiwan and S. Korea

Post Fukushima Japan

- Fleet of 54 reactors reduced to 42 operable
- 5 operating now: Sendai 1&2, Takahama 3&4, Ikata 3; Ohi 3&4, Genkai 3 startups in early 2018, NRA OKs first BWRs Kashiwazaki-Kariva 6&7, but may stay offline due to governor & mayor demands
- IEEJ Reference Scenario: 10 units in operation by March 2019, 7% nation's electricity vs. 30% prior to FD accident, NG impacts 3 Japan's Es: economy, energy security, environment
- High-case scenario: 17 units in operation by March 2019, CO2 emissions decreased by 45 million tons
- Paradoxical: Radiophobia, e.g. six years after FD evacuation orders still in place in several towns

Nova's FD Book: Vojin's Chapter

- Evaluates FD+60-year N safety record; Addresses lessons learned and unlearned
- FD: tsunami neglect, safety culture deficiency, slow use of PRA techniques, accident precursor ignored, Chernobyl forced evacuation lessons not learned: led to1600 deaths of evacuees
- Pursuit of absolute safety, radiophobia prevails, LNT hypothesis: no repair mechanisms in human body, "one of greatest scientific scandals of our time"
- 2017: Feb Executive Order 13777, April EPA seeking public comments, Sept N News Jerry Cuttler's & Bill Hannum's :"Current radiation protection limits: An urgent need for change"

Roadblocks: Cost Overruns

- After 60 yrs still construction delays causing massive cost overruns; 2/3 plants under way delayed
- First-of-the kind: US W AP1000s, French Areva EPRs
- March 29, 2017: W (87% Toshiba owned) filed for Chapter 11 bankruptcy
- Toshiba balance sheet minus $4.6bn, sale of memory chip unit ~$18bn US consortium offer; agreed to pay $2.168bn to Scana+Santee Cooper for Summer 2&3, $3.68bn to Southern Nuclear for Vogtle 3&4
- Chinese W AP1000s ~year late, but not affected
- Finnish TVO Areva EPR 9yrs late, French Flamanville 7yrs late; $4.8bn government infusion; EDF took over Areva's reactor business, New Areva fuel cycle

US Status

- 99 operating plants, ~102 GW, ~20% electricity, 475,000 jobs, 12 bn taxes; 60-year plant life extensions: 86 licensed, 6 under review, 5 expected; 80-yr NRC guidance; power uprates
- 21 Century N Renaissance fizzled: after Summer & Vogtle 8 COL licenses issued but no EPCs, 3 pending, 5 suspended
- Generation mix transformation, 1990s+much 2000s=~70% coal+nuclear; 2009 on shale gas revolution; 2016: coal 32%, gas 33%, nuclear ~20%, wind+solar 8%, hydro ~7%
- Market prices drop in 4 years + cheap gas killing merchant N plants: 12 well performing plants closed since 2012; NY+IL legislatures saved 4 closures, PA fuel secure bill, Conn, Ohio
- Yucca Mountain: licensing restart budgeted, 300 contentions; NM Interim spent fuel storage; DOE FERC request: Grid Reliability & Resiliency, favors baseload N & coal
- Generation IV: DOE+industry SMRs for ~2030; Nuscale SMR DC filed; HTGR+fast reactors nominally funded

Westinghouse Bankruptcy

- July 31: Summer 2 & 3: SCE&G (55%), Santee Cooper (45%) ceased construction of 2 half built W AP1000s, 9 yrs, $10.4bn spent despite Toshiba's $2.168bn parental guarantee: August 15: PSC petition withdrawn to allow review time
- Aug 29: Duke Energy, 11 unit owner, sought PSC to cancel Lee III plant (2 W AP1000), $542m spent, COL license issued
- Aug 31: Vogtle 3&4: Georgia Power(GP)-SN subsidiary 45.7%, Oglethorpe 30%, MEAG 22.7%, Dalton city 1.6% filed PSC recommendation to complete project; SN project mangm Bechtel construction; Toshiba $3.68bn settlement; operation Nov 2021/22; cost $19bn vs. 2008 estimate of $9.7bn; Vogtle 1&2 $1bn project turned into $8bn: great deal to ratepayers
- Oct/Nov 1: Toshiba payments, buys 10% KazAtom W shares
- Oct 2: Rick Perry announces $3.7bn Vogtle loan guarantees
- Nov 8: Georgia PSC announces Feb 6, 2018 Vogtle decision

Evolution of Soviet/Russian Reactors

- 1954: 5MW Obninsk reactor, world first nuclear electricity
- 1956-1970: 1st Gen VVER-440/V-230s, 1963-64 startups: 4 in Russia, 2 Armenia, 4 Bulgaria, 2 Czechoslovakia, 4 E Germany
- 1970-1980: 2nd Gen VVER-440/V213s, 1973 on startup (2 Russia, 2 Ukraine, 4 Hungary, 6 Czechoslovakia, 2 Finland)
- 1975-85: 3rd Gen VVER-1000s,22 Russia/Ukraine, 2 Bulgaria
- LGRs or RMBK-1000s (17): 11 Russia, 4 Ukraine, 2 Lithuania
- 1991-2: USSR breakup: 15 VVER-1000s cancelled/delayed
- Late 1990s: N revival: Gen III VVER-1000 (V320); AES-92 for India (2), AES-91 for China (2), V-446 for Iran
- 2000-2011 VVER-1000s building revived
- 2006: $55bn: VVER-1200 (V491&V392M)/AES-2006, MIR-1200
- 2010: Fast reactors with 4 coolants (Na, Pb, Pb-Bi, multiple); VVER-1300/AES-2010: VVER-TOI; icebreakers, merchant ship
- 2013: VVER-600; VVER-1500 & VVER-1800 designs but paused

Russia: Present Status

- 35 operating plants, ~27GW, 18.6% electricity; life extensions from 30 to 45-60 years; upratings 107-110%; 7 plants under way ~5.5GW; 45-50% by 2050, 70-80% century end
- 2017 Gen 3+: AES-2006 Novovoronezh II/1, Leningrad II/1
- 2018 FNPP: A. Lomonosov, Pevek 10,000t onshore structure
- 26 new builds planned (28.4GW): mostly VVER-TOIs, BN 1200s, FNNP Sakha; proposed 22 (21GW)
- Exports: $300bn, 34 in12 countries: 7 operating; 5 under way; 2016/17 backlog $137bn: 15 contracted: 4 Turkey (BOO), Egypt; 2 Iran, Bangladesh, 1 India, Finland (34% owner), Armenia; 11 ordered; 26 proposals; 50-90% financing
- Investment return: domestic 3 roubles/1 invested, exports 2
- Transition fast reactors: 14 GW by 2030, 34 GW by 2050, "Proryv" closed fuel cycle, BN-800 Beloyarsk-4 online, BN-1200 Beloyarsk-5 2020, BREST-300 lead, SVBR-100 lead/Bi

CHINA

- 37 operating ~33.6 GW; 8 online in 2016; 20 under way 58 GW by 2024; 150 GW by 2030; 2032 surpass US; 2040 PWRs level off at 200 GW, 2050 fast reactors 200 GW
- Coal reliant nation: 73%, 46% world coal production, 2 huge hydro Three Gorges 18.2 GW & Yellow River 15.8 GW
- Pollution: 1.6 million deaths/yr, 1 out of 5, economic loss 6% GDP, pursuit of N and renewables: 149 GW wind, 77 GW PV
- N Technology drawn from France (commercial 1994); from Russia, Canada, US; French based CPR-1000, ACPR-1000 Chinese designs; W based CAP1100 & CAP1400, Areva EPRs
- ACPR1000+ACPR1000+=Hualong One/HPR1000; 6 under way, 2019 Fuqing 5 online; 5 exports Pakistan, Argentina, UK
- 20 offshore floating plants: 60 MW, SMR ACRP50S
- Advanced Rs: 2x105MW HTR-PMs online 2017, 2X600 MW for 2021, 600MW Chinese Demo Fast Reactor 2023

France

- 58 plants operating, ~63,2 GW, 75% nation's electricity, world's largest electricity exporter 3 bn euros/yr, 17% electricity from recycled N fuel
- 1650 MWe Flamanville 3 underway, Penly 3 cancelled
- Former N Leader: Initially magnox reactors, then W PWRs, standardization, multiple unit sites, single utility EDF (85% gov), fuel cycle services + exports to S Africa, S Korea, China; Areva+Siemens developed EPR sold to Finland, France, China, UK
- EDF acquired British Energy with its AGR fleet
- Energy Transition for Green Growth: 50% N target with 63.2GW cap, Macron more realistic target, Fessenheim 1-2 shutdown when Flamanville online

UK

- First N industry leader, gas-cooled magnox + AGRs
- Wylfa, largest 26 magnox shutdown in 2015; EDF Energy bought British Energy, operates 14 AGRs+1 PWR 9 GW, all but 1.2GW retire in 2030; 2017 Renewables 30%+N 23.6 %=53.6% nation electricity
- 2025 coal phase-out, cuts in renewable energy subsidies, revival of N after ~30 years
- Hinkley Point C: 66.5% EDF, 33.5% CGN: 2 Areva 1600 MW EPRs license issued; 2 Sizewell C EPRs (20% CGN); Bradwell B UK HPR1000 CGN 66.5%
- NuGen: Toshiba, 3 W AP1000s, Moorside, GDA issued
- Horizon (Hitachi, JExel Nuclear): 2 1380MW ABWRs at Wylfa & Oldbury, Dec GDA, Wylfa site license
- Rolls-Royce announced UK SMR design program

South Korea

- 24 plants in operation, 22.5GW, ~1/3 nation electricity, 5 under way, ~7GW
- Imports ~97% energy, $170bn, N domestic source
- Korea Hydro & Nuclear (KNN), imports from US (W&CE), France, Canada, CE design standardized, Shin Kori AP1400, first Gen 3+ commercial
- President Moon after 5.8 earthquake: N phase-out: no new builds, plant life limited to 40 yrs, suspend Wolsong1 (legality disputed); Citizens (471) decision to complete 30% built Shin Kori 5&6 accepted
- UAE sale of 4 APR1400s, Barakah Units 1-4: #1&2 2018 online, #3 2019, # 4 2020; 25% UAE electricity
- EUR approved APR1400; reprocessing/enrichment?

India

- 22 operating plants, 6.2 GW, 18 indigenous PHWRs, 2 VVERs, 2 early GE BWRs, 7 under way: 4 PHWRs, 2 VVERs, FBR; 19 planned: 10 PHWRs, 3 VVERs, 2 EPRs, 2 AP1000s, 2 FBRs; 57 proposed including 10 VVERs
- 14.6 GW by 2024, 63 GW by 2032, 25% N by 2050
- Outside NPT, for 34 yrs excluded from N trade, until 2009; lack of indigenous uranium: fuel cycle to exploit thorium reserves; India's civil liability law vs. international conventions has limited imports of foreign technologies

Some Conclusions

- Growing consensus N to play major role in combatting climate change; it could provide 25% electricity by 2050; non-OECD countries to lead N growth: China, India, Russia, Middle East; most OECD countries lagging behind; World Energy Council (WEC): US & key EU countries on negative watch list
- Roadblocks: severe nuclear accidents, high capital costs with huge overruns outside China & Russia; additional high decommissioning costs, spent fuel disposal primarily US
- N in1960s unique carbon-free source without need for wind & solar; however, TMI, Chernobyl, & Fukushima accidents resulted in huge cleanup & decommissioning costs, expensive backfits, cancellations & phase-outs in several European & East Asian countries
- Wide interest in SMRs: e.g. US, UK, Canada; fast reactors in Russia, India, China