DaveVaglia@IEEE.org

Pittsburgh Section Region 2, IEEE

US Nuclear Power

A Renaissance?



David Vaglia







Safety Brief

• Be aware of your SURROUNDINGS



- Watch for cords and bags on floor
- Be cognizant of exits out of building





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Disclaimer



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Overview – From US Point of View

- 1. History of nuclear industry
- 2. Nuclear power plant designs
- 3. Impact of nuclear plant incidents on US nuclear power plants
- 4. Current status of nuclear industry
- 5. Upgrades/life extensions/new plants







History of US Nuclear Industry



- British physicist Ernest Rutherford is the father of nuclear science
 - 1904 he wrote "If it were ever possible to control at will the rate of disintegration of the radio elements, an enormous amount of energy could be obtained from a small mount of matter.
- Albert Einstein developed his theory in 1905 of the relationship between mass and energy E=mc²
- 1942, a group of scientists led by Enrico Fermi at the University of Chicago began construction on the world's first nuclear reactor, *Chicago Pile-1.*
 - In addition to uranium and graphite, it contained control rods made of cadmium.
- Development Of Nuclear Energy For Peaceful Applications began after World War II
 - Congress created the Atomic Energy Commission (AEC) in 1946.
 AEC authorized the construction of Experimental Breeder Reactor I
 - AEC authorized the construction of Experimental Breeder Reactor I which generated electricity on December 20, 1951.
- Nuclear research in the mid-1950s concentrated on showing that nuclear energy could produce electricity for commercial use.
- On May 26, 1958 the first commercial nuclear power plant in the United States, Shippingport Atomic Power Station, was opened



1960-1979 Golden Years for US Nuclear Plants

- 1960's private industry became more and more involved in developing light-water reactors after Shippingport became operational.
- Nuclear power continued to grow throughout the 1960s, the Atomic Energy Commission anticipated that more than 1,000 reactors would be operating in the United States by 2000
- 1974, the Atomic Energy Commission's development and regulatory functions were separated.
 - Department of Energy absorbed research and development
 - Regulatory branch was spun off and turned into an independent commission, the US Nuclear Regulatory Commission
- Most reactors began construction by 1974
- Today, nuclear power in the United States is provided by 100 commercial reactors
 - net summer capacity of 100,350 megawatts (MW)
 - nearly 20% of the nation's total electric energy generation in 2015
 - 66 pressurized water reactors
 - 34 boiling water reactors,





The Downside of the Story

- By the mid-1970s it became clear that nuclear power would not grow nearly as quickly as once believed.
 - Cost overruns were sometimes a factor of ten above original industry estimates
 - For the 75 nuclear power reactors built from 1966 to 1977, cost overruns averaged over 200%
- Of the 253 nuclear power reactors originally ordered in the United States from 1953 to 2008
 - 48 % were canceled,
 - 11 % were prematurely shut down,
 - 14 % experienced at least a one-year-or-more outage,
- Only about 25% of those ordered, or about half of those completed, are still operating and have proved to be relatively competitive
 - Competitive power pricing is pushing the nuclear plants out
- Costs of those plants that did not come to fruition rank as some of the largest managerial disasters in business history,
 - Paid for by consumers
 - Bankrupted some utilities that undertook the program
 - Started reformation of the power generation industry





1979 – Three Mile Island Incident

- Following the Three Mile Island accident in 1979 and changing economics, many planned projects were canceled.
 - More than 100 orders for nuclear power reactors, many already under construction, were canceled in the 1970s and 1980s, bankrupting some companies.
 - no ground-breaking on new nuclear reactors since TMI, (over 30 years) until
 - 2012, the NRC approved construction of four new reactors at existing nuclear plants.
 - Construction of the V. C. Summer Units 2 and 3 began in 2013.
 - And at the Vogtle Electric Generating Plant Units 3 and 4.
 - In addition, on October 2016 TVA's Unit-2 reactor at the Watts Bar became the first US reactor to enter commercial operation since 1996 (20 years).





History of US Electricity Market

- Prior to the turn of the century, the electricity service industry consisted of very efficient monopolies
 - Only a single, standardized electric grid was needed to connect each building.
 - Technology options were limited to steam-powered turbines fueled by coal and oil, or large hydro dams (Massive economies of scale).
 - There was very little long-distance transmission of power,
 - Each utility was responsible for electricity service within its own territory
- Growth in demand was exploding and monopoly utilities could wield the most cost-effective financing for new power plants.
 - These natural monopolies paid off for customers, with falling costs of reliable electricity even as demand rose
- Utilities justified investments in huge base load generating stations like nuclear and coal fired plants until...





U.S. Faces Several Major Energy Issues

- In the 1990s, as consumers grew increasingly dissatisfied with inefficiencies and cost overruns by traditional monopoly utilities,
- Congress sought to establish competitive wholesale electricity markets across the country, a big change to the 130-year history of the U.S. electricity system
 - This under minded the rationale for monopoly ownership and control, promoting competition between big players
 - Competitive markets transfer much of the risk of a costly and long-term power plant investment from the captive rate-payers of a vertically-integrated utility to competitive suppliers.
- To make nuclear more competitive, industry goals were set in the Energy Policy Act of 1992
 - maintain exacting safety and design standards
 - reduce economic risk
 - reduce regulatory risk
 - establish a high-level nuclear waste disposal program.
- Again, in 2005, the Federal Energy Regulatory Commission enacted the Energy Policy Act of 2005, the third major federal law enacted to promote wholesale competition.





The 21st century electricity system - Not there yet

- The scale of electricity generation is rapidly shrinking,
 - from coal and nuclear power plants that can power a million homes
 - to solar and wind plants that power a few hundred nearby homes.
- Electricity demand has leveled off,
 - every unit of new wind and solar displaces a unit of fossil fuel energy.
 - Batteries/electric vehicles provide for distributed energy storage
 - Smartphones/appliances allow customers to manage their energy use





The downside of the story, then the up swing

- Changes in the 1990s introduced retail sales "competition"
 - At times, that proved elusive as demonstrated by California's near-bankruptcy due to price manipulation by Enron and others
- Some states froze or reversed retail deregulation.
- Many states have shifted to regional, independent, nonutility delivery of energy services known as either
 - Independent System Operators (ISOs) or
 - Regional Transmission Organizations (RTOs).
 - offer independent oversight of electricity sales and industry transactions,
 - equal access to the power grid for all power suppliers,,
 - incentives for new generation and increased reliability across the region.





US ISOs and RTOs



Electricity Market Status Today

- Competition will continue to be one of the dominant issues facing the electric power industry.
- Many organizations, federal, state, & regional governments, suppliers, distributors, consumers involved,
- Objective is to develop policies that:
 - Give all suppliers an opportunity to compete
 - Give all customers an opportunity to benefit from the competition.
 - Support the goals of the NATIONAL ENERGY POLICY????
 - .,that is what needs done first!!!!





Signs of the Nuclear Renaissance?

- As of October 2014, the NRC has granted license renewals providing a 20-year extension to a total of 74 reactors.
- In early 2014, the NRC prepared to receive the first applications of license renewal beyond 60 years of reactor life,
- 2016
 - 4 new reactors are under construction
 - U.S. newest nuclear power reactor, Watts Bar Unit 2, completed ascension tests and was ready to enter into pre-commercial operations



Watts Bar Units 1 & 2





Or a Renaissance in Reverse?

- 2013 Four companies announced nuclear plant closures, eight plants in total, the first shutdowns in 15 years,
 - Kewaunee, the first retired reactor just received a 20 year life extension
- Decisions to forgo uprates and plant life extensions indicate that the Nuclear Renaissance has not produced a new fleet of reactors
 - This Renaissance is failing to keep the existing fleet operating
- The problem with nuclear lies in economics
- The good problem that the US has is the abundant availability of diverse lower cost alternatives



San Onofre Nuclear Generating Station, Units 2 and 3,Southern California Edison, shut down 2013



September, 2016 Power Industry Headlines

- PG&E files plans to shutdown nuclear plant (Diablo Canyon)
- First offshore wind farm a sign of things to come
- Exelon to buy FitzPatrick Nuclear Plant
- Natural gas generation rises to new high in July
- EDF orders 80 Vestras Wind turbines for US projects
- Kentucky Utilities to cap remaining coal ash ponds
- Amazon Data Centers powered by new wind farm
- Kemper power station (coal gasification) to cost \$6.8 billion, original estimate \$2.9 billion
- Duke Energy completes Los Vientos Wind Power projects





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Department of Energy's Report on the Future of Advanced Nuclear Technology

- DOE concluded that deployment of new technology "at a significant rate" in the period of 2030 to 2050 requires - competitive cost based on lower construction costs

 - monetary recognition of nuclear power as a benefit to reducing carbon emissions.
- Both points imply nuclear without subsidizes or government regulation is not economically competitive
- The report said that energy market rules that vary around the country "make it challenging to value base load nuclear generation appropriately."
- These rules have led to early U.S. plant retirements and discouraged development and investment in new plants."
 - examples included rate structures in wholesale capacity markets, driven low by lower cost suppliers
 - preferential dispatch rules for renewable generation, ensuring renewables with no "fuel" costs are used
 - rates that are inadequate to assure recovery of investment (for nuclear).
- All of these points have the same root issue, which is in the US, nuclear is not competitive with the mix of other energy supplies







DOE's Future Map of Advanced Nuclear Technology Report Recommendations

- Advanced technology has an opportunity to lower overnight capital costs by as much as 30 percent compared with large light water reactors,
- Plant thermal efficiencies could be increased by 30 percent and safety improved by a factor of 10 when measured by the number of incidents per year
- Other gains include higher-temperature operation and fuel utilization (perhaps a factor of 50 percent or greater for some advanced concept/fuel cycles)."
- Over the last decade, a "nuclear renaissance" was touted that made extremely optimistic claims about nuclear reactor costs being competitive with other options based on:
 - New nuclear reactors could be built quickly and at relatively low cost.
 - New Nuclear reactors would run at very high levels of capacity for long periods of time with very low operating costs.
- However, construction cost estimates, construction difficulties, and delays in virtually all market economies where construction of a handful of new nuclear reactors was undertaken have proven these assumptions wrong.
- Recent decisions to retire aging reactors early show that the second assumption was not true of the first generation of nuclear plants
- That calls into question the extremely optimistic assumptions about the operation of future nuclear reactors.





Better Designs from Evolved Technology







Types of Power Reactors (Worldwide)

	# Units	Net MWe	# Units	Net MWe	# Units	Net MWe
Reactor Type	(in operation)		(forthcoming)		(total)	
Pressurized light-water reactors (PWR)	276	256,649.33	88	92,947.00	364	349,596.33
Boiling light-water reactors (BWR)	80	76,008.90	6	8,056.00	86	84,064.90
Gas-cooled reactors, all models	15	8,025.00	1	200.00	16	8,225.00
Heavy-water reactors, all models	48	23,945.00	9	5,772.00	57	29,717.00
Graphite-moderated reactors, all models	15	10,219.00	0	0.00	15	10,219.00
Liquid-metal-cooled reactors, all models	1	560.00	5	1,616.00	6	2,176.00
Totals	435	375,407.23	109	108,591.00	544	483,998.23

Pressurized Water Reactors most common





Pressurized Water Reactor (PWR)



- Water pumped though reactor is pressurized and does not boil
- Intermediate heat exchanger creates steam for generating electricity
- Primary reactor coolant stays inside containment

Operating Plants World ~276 US ~70 Japan ~24





Boiling Water Reactor (BWR)



Operating Plants World ~80 US ~34 Japan ~26 Water pumped though reactor is allowed to boil and steam passes directly through turbine, generating electricity

Primary reactor coolant exits containment as steam and reenters water

 In general, BWRs have smaller containment structures than PWRs since they do not have the large steam generator heat exchangers nor the pressurizer that the PWRs have





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Impact of Nuclear Plant Incidents on US Plants

- 1. Three Mile Island (TMI)
- 2. Chernobyl
- 3. Fukushima Daiichi







Impact of Three Mile Island (TMI) on US Plants





- Shaped the safety culture of the nuclear power industry today.
 - Changed the industry's mind-set from one of selfassuredness to one of increased vigilance
- Operator training improvements, which give operators a better understanding of both the theoretical and practical aspects of plant operations
- Sharing of industry knowledge to promote excellence in plant operations TMI led to the establishment of the Institute of Nuclear Power Operations (INPO) and its National Academy for Nuclear Training

Control rooms designed with human factors in mind. TMI vintage control rooms were poorly organized, and did not provide important information.

- New reactors have control rooms have Human Factored designs and employ computer technology that prioritizes the information operators receive.
- Human-System Interface Design Review Guidelines (NUREG-0700)





The Other Incident

- 30 years ago Chernobyl 4 (Ukraine) was destroyed because of an improperly conducted experimental test
- The NRC's post-Chernobyl assessment emphasized the importance of several concepts, including:
 - designing reactor systems properly on the drawing board and implementing them correctly during construction and maintenance;
 - maintaining proper procedures and controls for normal operations and emergencies;
 - having competent and motivated plant management and operating staff; and
 - ensuring the availability of backup safety systems to deal with potential accidents.







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Fukushima Daiichi - 6 BWRs



March 11th, 2011 – Tohoku Earthquake

Duration	6 minutes [[]	} Russia
Magnitude	9.0	Viadrvostok
Depth	32 km (20 mi)	N
Tsunami	Wave 7+ m	Chongjin
Run-up to	40.5 m	Kimchaek
Foreshocks	7	China West A
Aftershocks	1,235	South Korea
Casualties		Ulchin -
deaths	>15,700	
injured	>5,700	Taegu Wolsong Shimane
missing	>4,600	Kori Takahama Hiroshima
		Shimonoseki





Fukushima's Daini/Daiichi Plants – Common Threads

- Plant Designs?
 - Plants were not designed to withstand the 40-foot tsunami that struck
 - Power was knocked out by the quake
 - Tsunami destroyed the diesel back-ups
- Human Factors?
 - Japanese decision-making process might have been a hindrance
 - group decision-making
 - not individual decision-making
- Training?
 - There was no prior planning or staff training for such an event,
- Readiness?
 - No pre-staged portable equipment such as that added at U.S. plants after the 2001 terrorist attacks,
 - Only limited off-site support for supplying equipment.
- Site Conditions?
 - Conditions at Fukushima Daini were not drastically different than at its sister plant six miles up the coast of Japan





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Fukushima Daiichi – What Went Wrong

- Four of six reactors were damaged
- Three of six reactors sustained core damage
- Heroic Effort Workers scavenged batteries out of wrecked cars and hot wired them to the instrumentation to determine critical parameters and to control the pumps to cool reactors



- Human Factors?
 - Disagreement and confusion over who should be calling the shots
 - Many of the staff were contractors and were released from site so they could go to find their families
 - At low point, less than 70 workers were on site





Fukushima Daini – What Went Right

Four out of four reactors brought to safe shutdown

- Unit 3 had partial AC power and a partially operable residual heat removal system, control room operators brought it to an orderly shutdown.
- Units 1, 2 and 4, were without power, and core temperatures were rising
- One incoming transmission line was energized, but weak and fluctuating.



- Human Factors?
 - Strong active leadership during the crisis by site superintendent Naohiro Masuda
 - In-depth knowledge of the station

 - Motivated personnel who took extraordinary actions (400 stayed on site)
 In a period of 30 hours, plant staff replaced residual heat removal pump motors and laid and energized 5.5 miles of heavy-duty electric cables





Plant Life Extensions

- The feasibility of replacing major components, such as steam generators in PWRs has driven the license renewals extending the lifetimes of existing plants.
 - Most nuclear power plants originally had a design lifetime of 25 to 40 years, but engineering assessments have established that many can operate longer
- In the USA, over 75 reactors have been granted license renewals
 - Extends their operating lives from the original 40 out to 60 years
- License extensions at about the 30-year mark justify significant capital expenditure for replacement of worn equipment and outdated control systems

License Renewals Granted for Operating Nuclear Power Reactors



Fix up that old car and drive it a few more years. Its cheaper than buying a new one.



Increased Capacity



Uprating a plant can be done by:

- MUR or "Measurement Uncertainty Recapture": Done by adding more accurate instruments into a plant, and gain back 1 percent or so power
- "Stretch": This uprate uses the installed equipment to a higher degree of its maximum capability. These are a few to several percent power increases.
- "Extended Power Uprate": This is a major redo of plant components, including replacement of steam generators, upgrading of the turbine generator, and perhaps other plant systems too such as pumps. It's a major investment, but the payoff can be big.
- Uprating is a highly cost-effective way of bringing on new generating capacity.
 - Goes hand in hand with Plant Life Extensions
- The Nuclear Regulatory Commission has approved more than 140 uprates totaling over 6500 MWe since 1977, a few of them "extended uprates" of up to 20%.

You can teach an old dog new tricks!





New Build Sanmen 1







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Energy Plans?

- Hillary Clinton describes herself as "a proven fighter against the threat of climate change,"
- Abide by the Paris accord limiting global carbon emissions
- Expand investment in renewable energy
- Ban drilling in the U.S. Arctic
- Block attempts to resurrect construction of the Keystone XL pipeline
- Supports nuclear energy
 - Does not want any nuclear power plants to close prematurely...would make it harder and costlier to build a clean energy future"
 - Supports the President's Blue Ribbon
 Commission dealing with nuclear waste



- Donald Trump says he does not believe that climate change is a significant environmental challenge, and he doubts that humans are contributing factors.
- Withdraw from the Paris accord limiting global carbon emissions
- Increase in production of fossil fuels, including off-shore drilling
- Remove carbon emissions limits on US power plants
- Finish construction of the Keystone XL pipeline
- "I'm in favor of nuclear energy, very strongly in favor of nuclear energy." In same interview, Trump stated that he favored development of natural gas over nuclear energy



