Chernobyl and Fukushima — The Legacy in The UNS Nuclear Reactor Fleet

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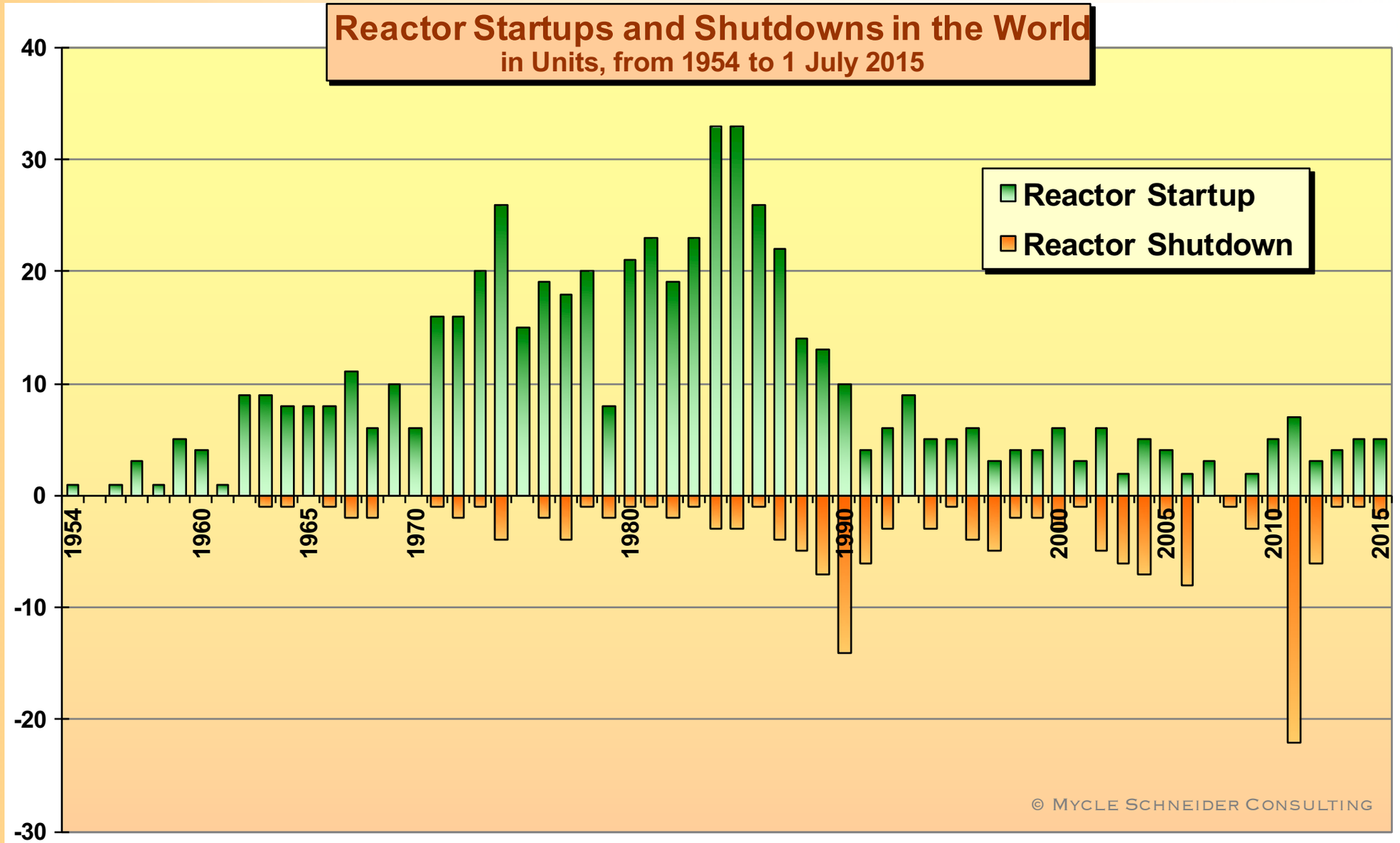
Overview

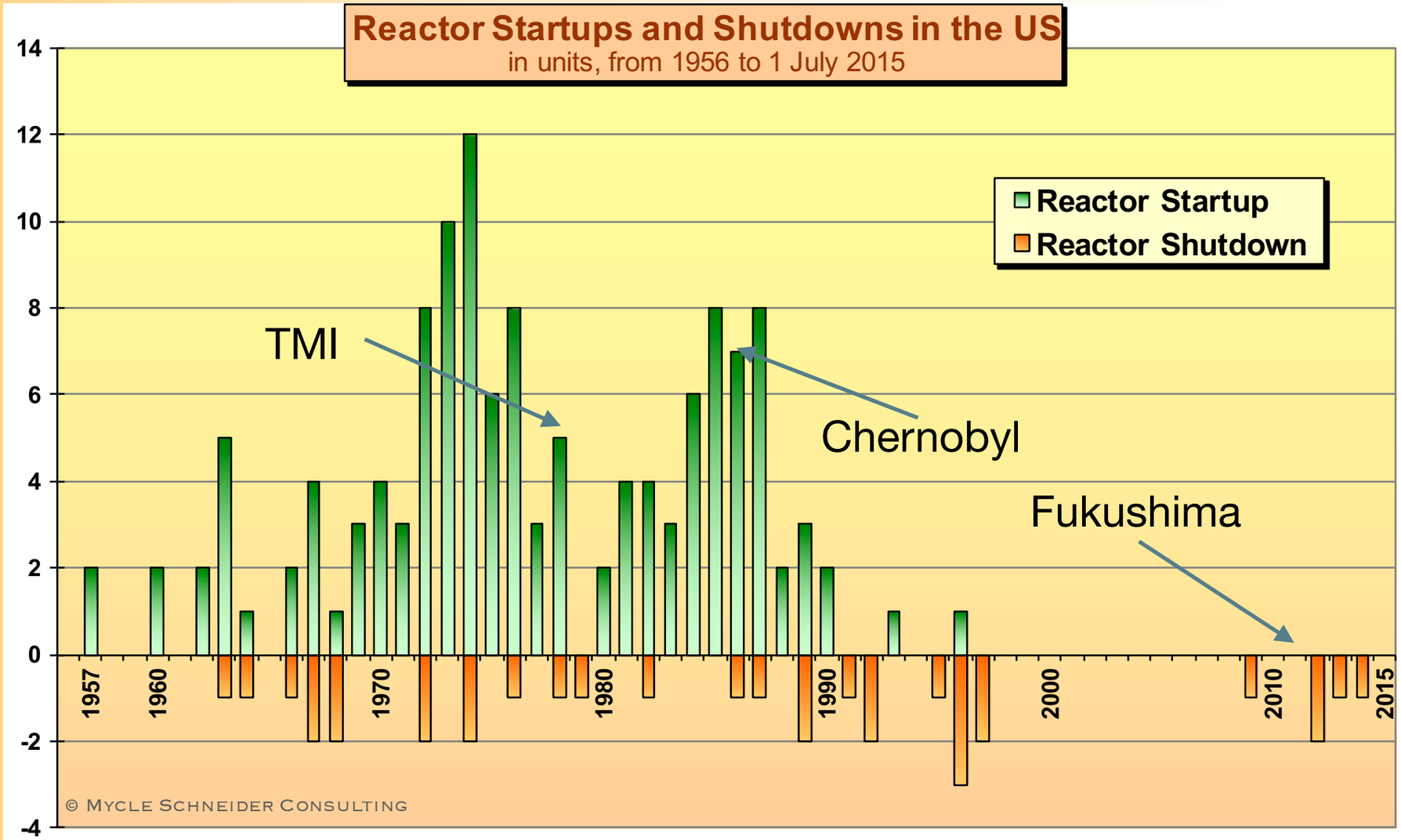
- Three Mile Island
- Chernobyl
- Fukushima
  - The US role in Japan
  - The US actions
- Status of US Fleet Today

History of Nuclear Power in the World



Source: IAEA-PRIS, MSC, 2015

History of Nuclear Power in the United States



Source: IAEA-PRIS, MSC, 2015

Three Mile Island

- There was a significant impact from the accident despite only limited amounts of radioactivity being released
- There was a moratorium on new plant licensing and temporary shutdown of similar reactor designs
- Significant changes to the nuclear regulatory system
  - NRC reforms
  - INPO created
  - FEMA established and Emergency Preparedness dramatically changed
- Decommissioning and fuel removal not complete until 1991 costing $1 billion

Chernobyl

- Chernobyl accident was largely dismissed in the United States
    - Two major reports were done.
        1. Analysis of the accident events and causes — January 1987

“The phenomenon associated with the Chernobyl accident were greatly influenced by design features and materials unique to the RBMK-1000 reactor which differ…from those of U.S. reactors…The Chernobyl data on radionuclide releases are not directly relevant to the predicted releases from the US reactors because of fundamental differences in release mechanisms and barriers to the release to the environment.”

Chernobyl

2. Assessment of Needed Changes — April 1989

“(1) No immediate changes are needed in the NRC's regulations regarding the design or operation of U.S. commercial nuclear reactors.
Nuclear design, shutdown margin, containment, and operational controls at U.S. reactors protect them against a combination of lapses such as those experienced at Chernobyl… Assessments in the light of Chernobyl have indicated that the causes of the accident have been largely anticipated and accommodated for commercial U.S. reactor designs.

(2) Some aspects of requirements and regulations that already exist or are being developed will be reexamined, taking into account the accident at Chernobyl.

(3) Study of areas related to certain aspects of the Chernobyl accident will be extended and will provide a basis for confirming or changing existing regulations.

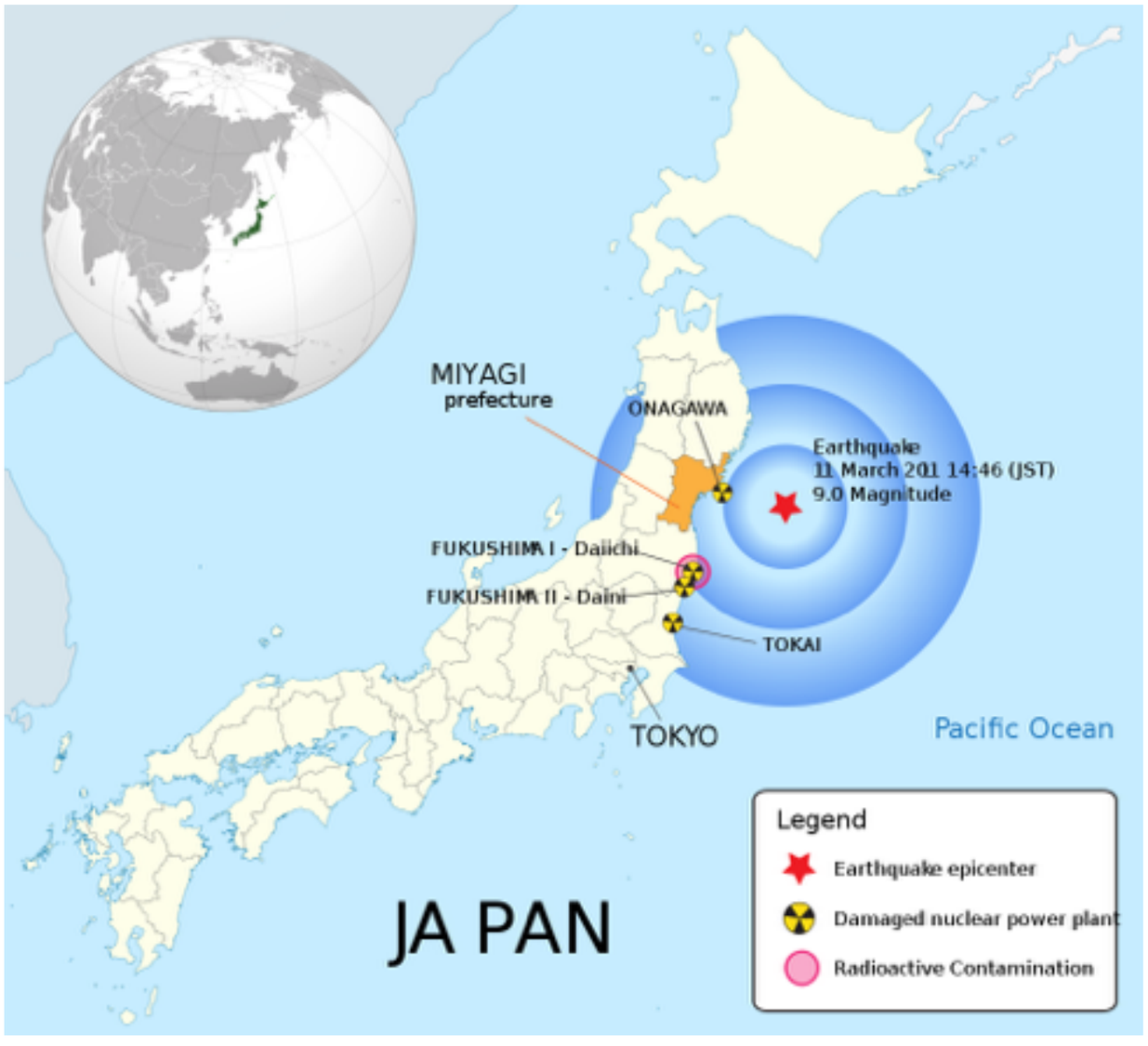
(4) The Chernobyl experience should remain as part of the background information to be taken into account when dealing with reactor safety issues in the future.

==> Chernobyl led to no real changes in the United States

Fukushima Daiichi Accident

- A 9.0 magnitude earthquake occurred off the coast of Japan on March 11, 2011

- The earthquake triggered a tsunami which directly impacted four nuclear plant sites in Japan



Fukushima Daiichi Site

- 6 General Electric Boiling Water Reactors at the site
  - 1 BWR 3, 4 BWR 4 all with Mark I containment
  - 1 BWR 5 with Mark II containment — unit 6
- only units 1,2,3 were in operation
- unit 4 had all the fuel in the spent fuel pool

Fukushima Accident

- The primary issue was a loss of all power to and on the site
  - the earthquake disabled bulk power transmission to the site
  - the flooding and impact of the tsunami disabled the backup system
    - diesel generators were lost —> power to motors for pumps and valves were lost
    - batteries were lost —> no lights and no instrumentation

Fukushima Daiichi Accident

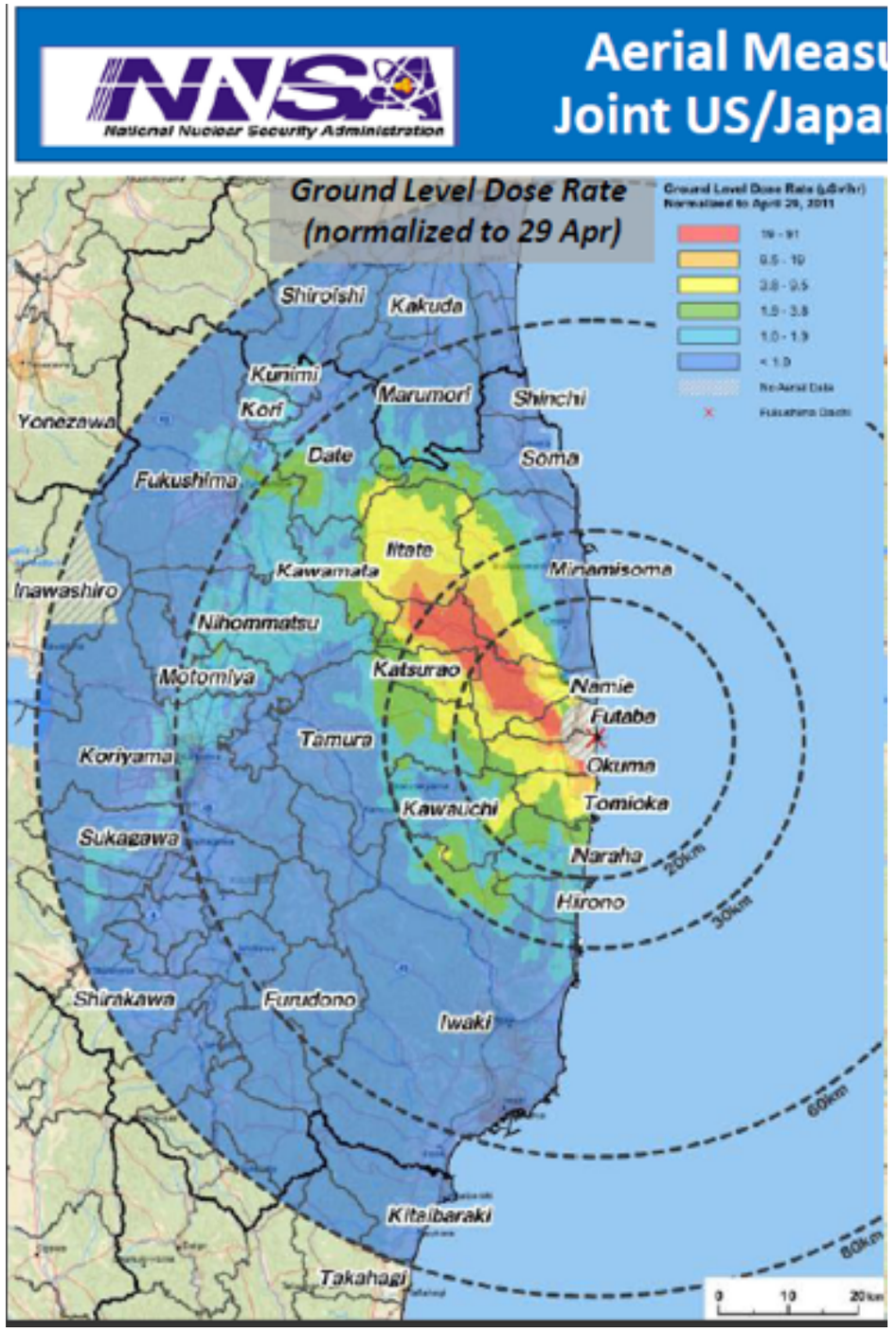
- Hydrogen explosion in Unit 1 really set the plant on a path to severe accident

Fukushima Accident - US Response

- There were two primary issues the NRC and US government were concerned about
  - extent of radiation contamination —> 50 mile recommendation
    - significant contamination of land around the reactor sites
  - the condition of the spent fuel pools
    - spent fuel fires can cause widespread contamination
- possible evacuation of Tokyo - an unthinkable scenario
  - was it possible? some in Japan thought so…

Fukushima Accident — 50 Mile

- On Wednesday March 16, the US government recommended US citizens stay at least 50 miles away from the reactors
  - very different from the initial Japanese government evacuation instruction
  - very controversial in the US because US plants are required to prepare for 10 mile evacuations



Fukushima Accident Domestic Response

- On March 21, the Commission met to receive a briefing on the accident

- Two days later the Commission issued a unanimous direction to create a short and long term task force to review the accident

- Only the short term task force ever finished

Fukushima Accident — Response

6. SUMMARY OF OVERARCHING RECOMMENDATIONS

This section presents the Task Force's recommendations for improving the safety of both operating and new nuclear reactors. It also addresses recommended improvements in the NRC programs for the oversight of reactor safety. The recommendations are based on the Task Force's evaluations of the relevant issues identified from the Fukushima accident. Appendix A of this report proposes an implementation strategy and offers further details on these recommendations.

The Task Force makes the following overarching recommendations, as stated in the preceding sections of this report:

Clarifying the Regulatory Framework

1. The Task Force recommends establishing a logical, systematic, and coherent regulatory framework for adequate protection that appropriately balances defense-in-depth and risk considerations. (Section 3)

Ensuring Protection

2. The Task Force recommends that the NRC require licensees to reevaluate and upgrade as necessary the design-basis seismic and flooding protection of SSCs for each operating reactor. (Section 4.1.1)
3. The Task Force recommends, as part of the longer term review, that the NRC evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods. (Section 4.1.2)

Enhancing Mitigation

4. The Task Force recommends that the NRC strengthen SBO mitigation capability at all operating and new reactors for design-basis and beyond-design-basis external events. (Section 4.2.1)
5. The Task Force recommends requiring reliable hardened vent designs in BWR facilities with Mark I and Mark II containments. (Section 4.2.2)
6. The Task Force recommends, as part of the longer term review, that the NRC identify insights about hydrogen control and mitigation inside containment or in other buildings as additional information is revealed through further study of the Fukushima Dai-ichi accident. (Section 4.2.3)
7. The Task Force recommends enhancing spent fuel pool makeup capability and instrumentation for the spent fuel pool. (Section 4.2.4)
8. The Task Force recommends strengthening and integrating onsite emergency response capabilities such as EOPs, SAMGs, and EDMGs. (Section 4.2.5)

Strengthening Emergency Preparedness

9. The Task Force recommends that the NRC require that facility emergency plans address prolonged SBO and multiunit events. (Section 4.3.1)
10. The Task Force recommends, as part of the longer term review, that the NRC pursue additional EP topics related to multiunit events and prolonged SBO. (Section 4.3.1)

11. The Task Force recommends, as part of the longer term review, that the NRC should pursue EP topics related to decisionmaking, radiation monitoring, and public education. (Section 4.3.2)

Improving the Efficiency of NRC Programs

12. The Task Force recommends that the NRC strengthen regulatory oversight of licensee safety performance (i.e., the ROP) by focusing more attention on defense-in-depth requirements consistent with the recommended defense-in-depth framework. (Section 5.1)

Fukushima Accident — Response

- Three orders issued in March 2012

  1. Spent fuel instrumentation

  2. Interim enhancements of b5b

  3. Hardened vents for Mark I and II BWR designs

- Remaining issues being addressed through longer term actions

Fukushima Accident Domestic Response

- Station Blackout Rulemaking — the most crucial of all the issues
  - Current requirements only demand US plants “cope” with total loss of electrical power for eight to sixteen hours.
    - That is far too short based on the Fukushima accident
    - Task Force recommended 72 hour “coping” time
- Current rulemaking proposal would not adopt a new coping time, but focus on mitigating station blackout events
- Rulemaking not anticipated to be completed until 2017
- Then plant modifications will need to be made, a process that could take an additional number of years.

Fukushima Accident Domestic Response

- Seismic Reevaluations
  - Deterministic plant modifications to be done by Dec 2016 for Central and Eastern US plant for modifications not requiring outages.
  - Modifications requiring outages get another 2 outages to be completed after Dec 2014.
    - 2 outages is between 3 and 4 more years, so Dec 2017 to Dec 2018.
    - True sophisticated evaluations will not be done for years after. Some plants not until 2020. That doesn't even include the needed plant modifications
- Filtering of Hardened Vents
  - Commission rejected
- Majority of the post-Fukushima reforms are being done through an industry voluntary initiative to stage portable equipment to provide emergency power and water supplies

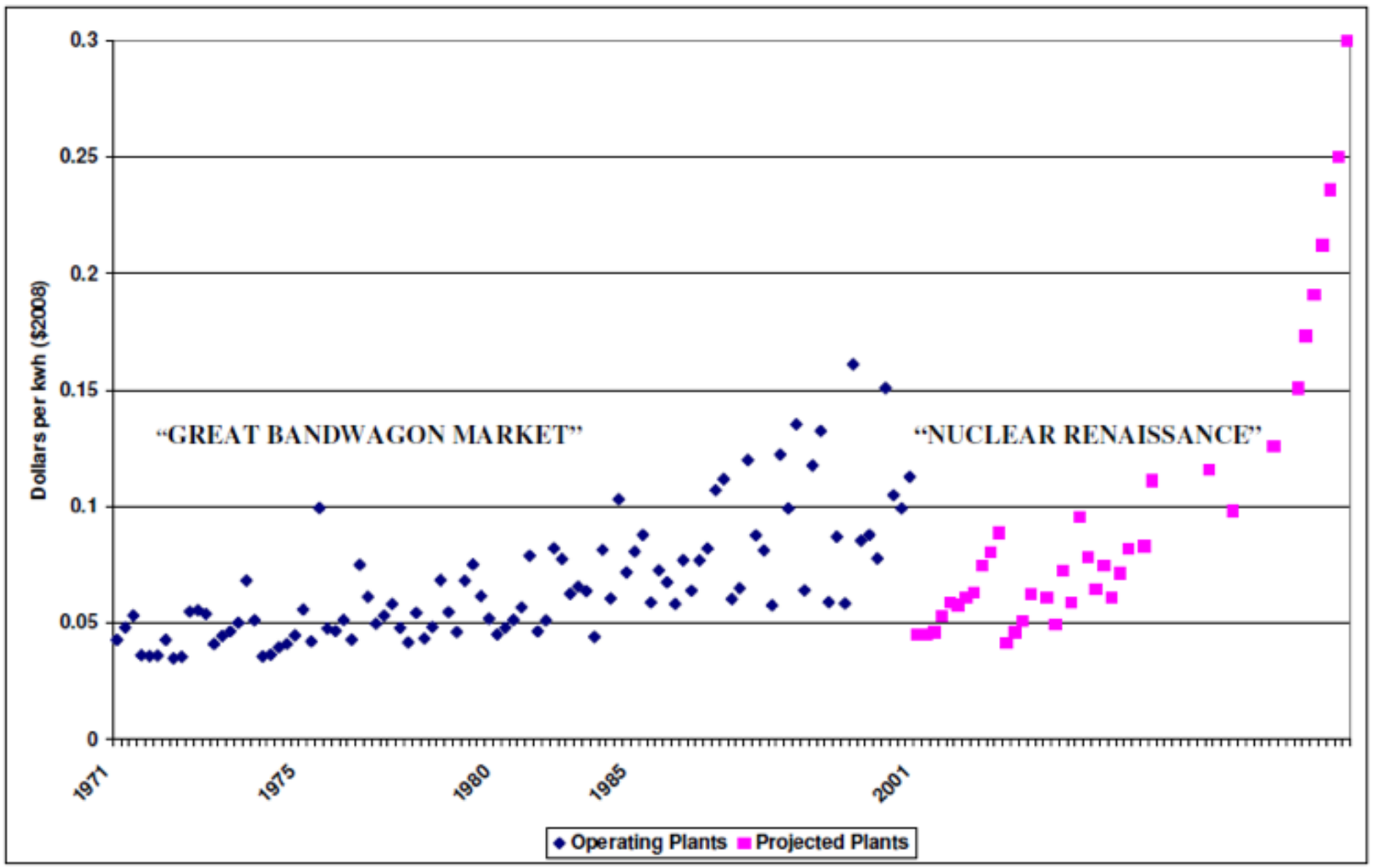
Fukushima happened in March 2011.

Why?

1. Three Mile Island reforms were generally viewed as poorly thought out and poorly implemented

2. In the United States, costs are the primary factor in electricity production decisions

    - Nuclear costs are not decreasing



(Cooper, Vermont Law School, 2009)

Economics of existing plants are very poor

There have been a number of recent or planned plant closures in the United States

- Vermont Yankee due to economic considerations
- Kewaunee due to economic considerations
- San Onofre unit 2 and 3 due to safety concerns
- Crystal River due to safety concerns
- Oyster Creek scheduled to shutdown in 2019
- Pilgrim schedule to shutdown in 2019
- Fitzpatrick schedule to shutdown in 2017

New Reactors Instead?

- There are currently 4 newly licensed reactors under construction in the U.S.
  - 2 at the Vogtle plant site in Georgia
  - 2 at the V.C. Summer plant site in South Carolina
- Both plants are using the AP1000 design by Westinghouse
- Major test for future of nuclear — plants need to be built on time and on budget
- An unfinished 1970s plant is also being completed

New Reactors Instead?

Plant Vogtle 3 and 4 construction site.

February 2014 ©2014 Georgia Power Company All rights reserved

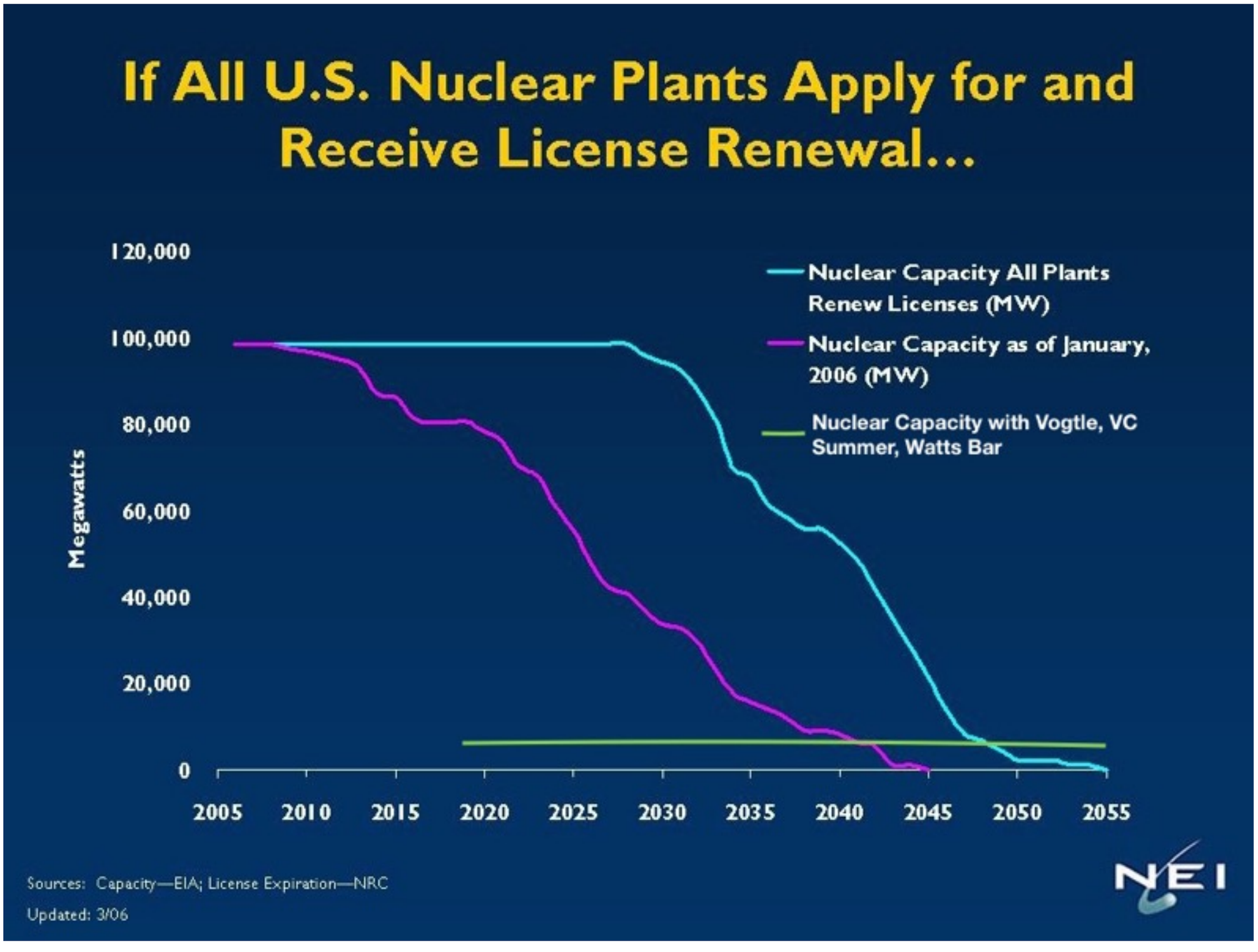
Vogtle Unit 3 nuclear island (left) and turbine building (right).

March 2015 ©2015 Georgia Power Company All rights reserved

New Reactors Status

- To truly spur a nuclear revival, Vogtle and V.C. Summer needed to be built without a doubt on time and on budget
- How are they doing? FAILING
    - Vogtle is at least 3 years behind schedule with at least $3 billion in cost overruns
        - problems were largely the result of modular construction
    - Vogtle 3 is expected to come online in 2020, Vogtle 4 one year later
    - V.C. Summer is similarly behind schedule and over budget
- Capacity cost is over $5500/kW for about 1100MWe
- Natural gas combined cycle, nominally 340 MWe
        - $1000/kW without carbon capture
        - $2000/kW with carbon capture and storage

Future Trend of US Nuclear Power



Conclusion

- Neither the Chernobyl nor Fukushima accident has had a significant affect on the future of nuclear power in the United States

- While initial reform efforts for Fukushima were promising delays in implementation have weakened the remaining actions

- Decisions in the US about nuclear plants will largely be driven by economic factors in the future