

Are We Safer Now?
The Future of Nuclear Power in
the Northwest 3.5 Years After
Fukushima

Edwin S. Lyman
Senior Scientist
Union of Concerned Scientists
October 2014

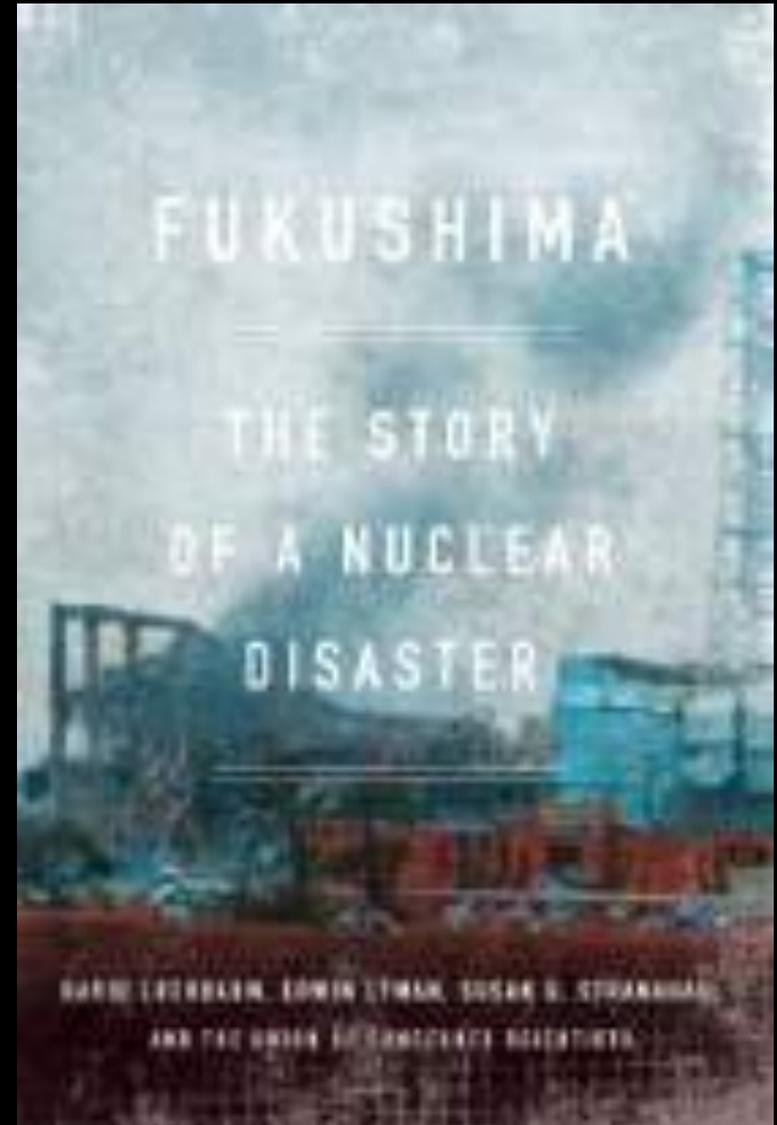
Fukushima: Why should we care?

- **Because if we don't, it will only be a matter of time before a similar event happens here:**
 - **U.S. nuclear plants are vulnerable to catastrophic natural disasters, multiple system failures or large terrorist attacks**
 - **U.S. nuclear plants are not much better equipped than Japanese plants to cope with severe accidents**
 - **U.S emergency plans are not designed to protect the public after Fukushima-scale accidents or fully address the problem of long-term land contamination**

FUKUSHIMA: The Story of a Nuclear Disaster

David Lochbaum
Edwin Lyman
Susan Q. Stranahan

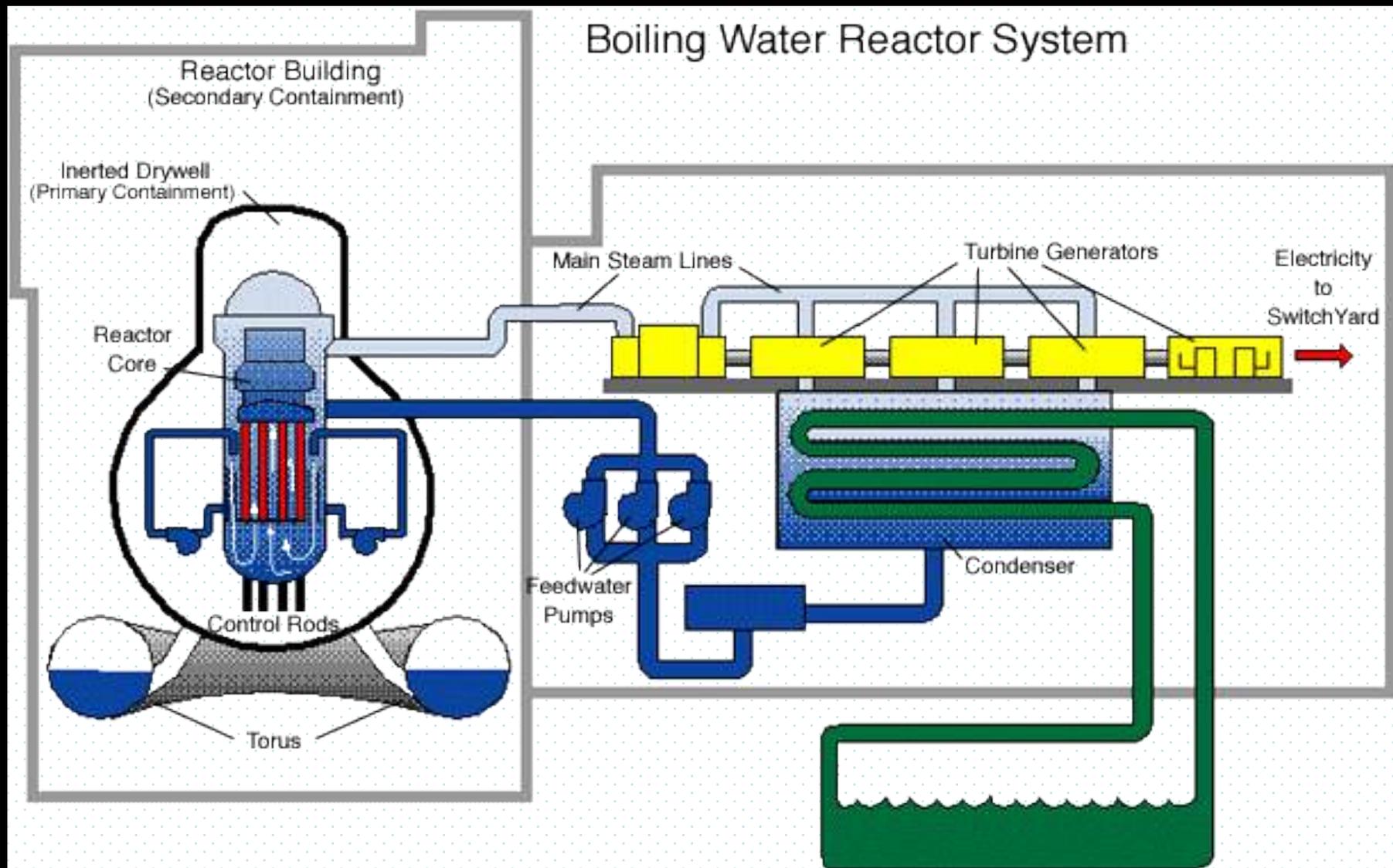
The New Press (2014)



About the book

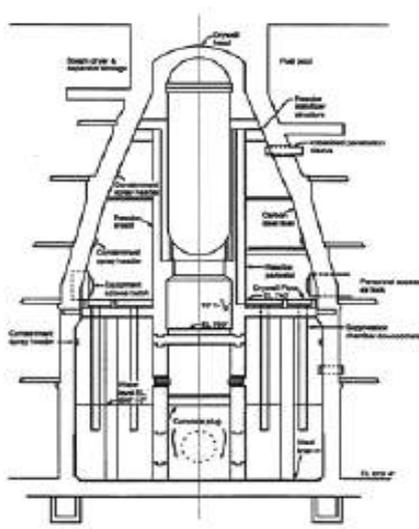
- A two-year collaboration between UCS nuclear experts and accomplished journalist Susan Q. Stranahan
- Based on exhaustive research, technical analysis, interviews and reviews of thousands of pages of documents released by Nuclear Regulatory Commission (NRC) and other U.S. government agencies, the Tokyo Electric Power Company and independent commissions
- “The book is a gripping, suspenseful page-turner finely crafted to appeal both to people familiar with the science and those with only the barest inkling of how nuclear power works ...” – *Kirkus Reviews*

GE Mark I boiling-water reactor

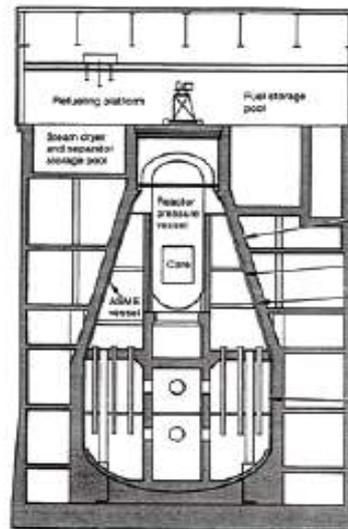


GE Mark II boiling-water reactor

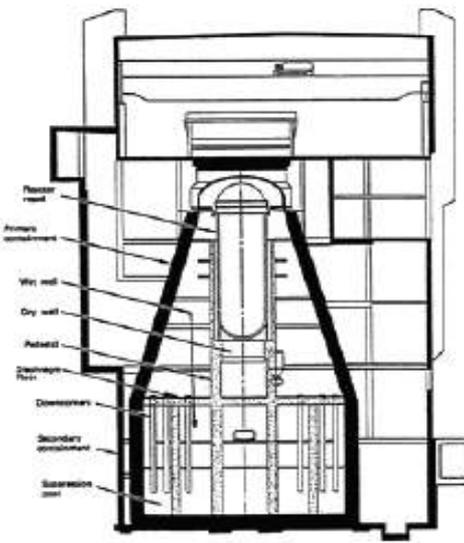
Mark II Design More Unified than Mark I Design (continued)



LaSalle Units 1 & 2



Columbia (WNP-2)



Limerick 1 & 2

Columbia Generating Station (Mark II BWR)

- CGS is unique among U.S. Mark II BWRs
 - Free-standing steel drywell
 - Smallest volume-to-power ratio
- This design combines the worst aspects of Mark I and Mark II containments
 - Drywell melt-through (Mark I)
 - Suppression pool bypass (Mark II)

The Accident: March 11, 2011

- 9.0 magnitude earthquake caused all 6 boiling-water reactors to lose off-site electrical power
- Emergency backup diesel generators started
- Less than one hour later, a 50-foot tsunami flooded the diesel generators at reactors 1 to 5, and much of the electrical distribution system
- Led to loss of all power (except for some batteries for limited times)
- “Station Blackout”



Inundation

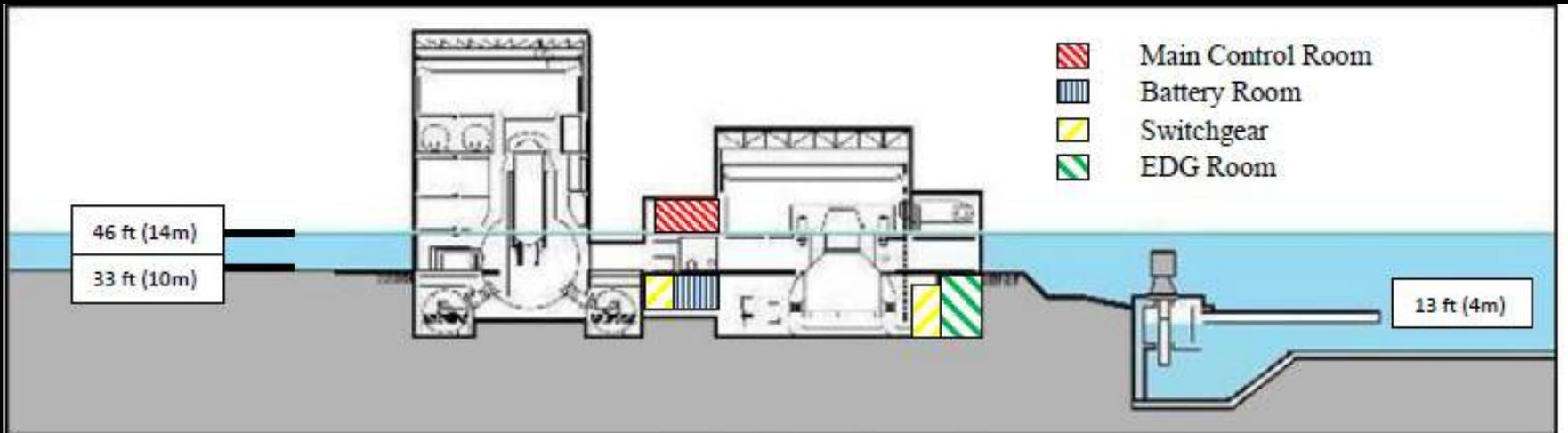


Figure 3.3-1 General Elevations and Inundation Level

Station blackout

- Nuclear reactors generally utilize AC power from the grid to operate motor-driven equipment
- Failure of all AC power: “station blackout”
- Only source of electricity is DC battery power
 - Can maintain instrumentation, controls and lighting
 - Enables use of steam-driven pumps
 - Only lasts from 2-8 hours, depending on the charge
- However, at Fukushima
 - DC power and electrical circuits were partially lost because of flooding
 - “ultimate heat sink” (seawater pumps) also lost

Severe accident management

- Once DC power is lost, core meltdown will eventually occur unless power or cooling is restored before fuel damage occurs
 - Portable power supplies, diesel fire pumps, fire engines
 - Manual manipulation of containment vent valves and reactor vessel safety relief valves
 - Manual control of steam-driven systems (e.g. Reactor Core Isolation Cooling, or RCIC)
- Fukushima demonstrated the practical difficulties of carrying out such actions under challenging circumstances

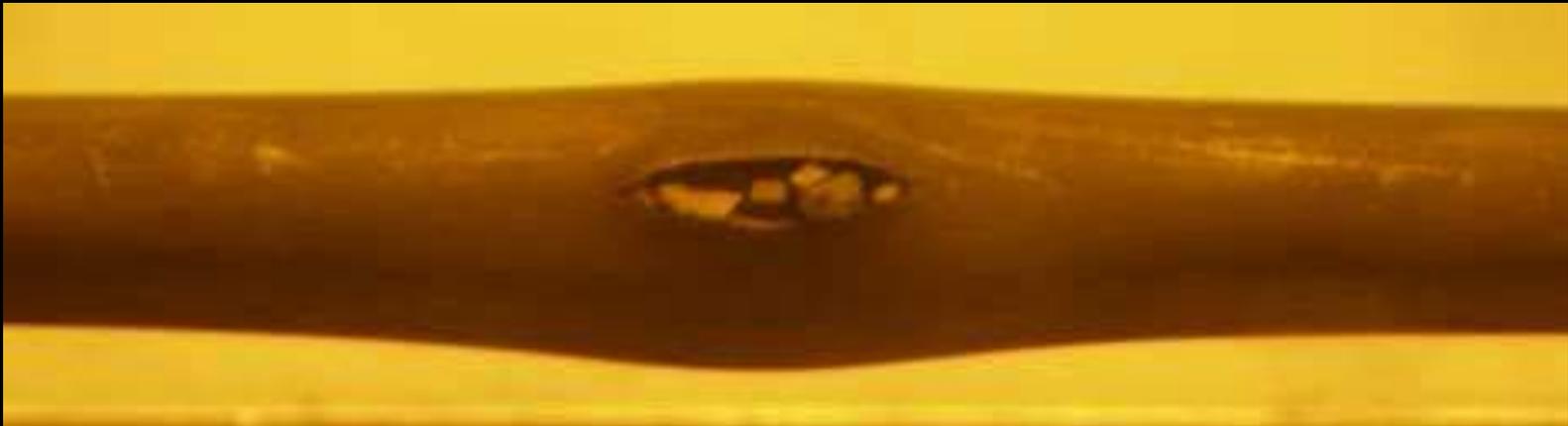
Attempts at Recovery



- **Emergency DC power using scavenged car batteries**
- **Emergency water injection with diesel fire pumps, fire engines, helicopters**
- **Manual operation of containment vent valves**

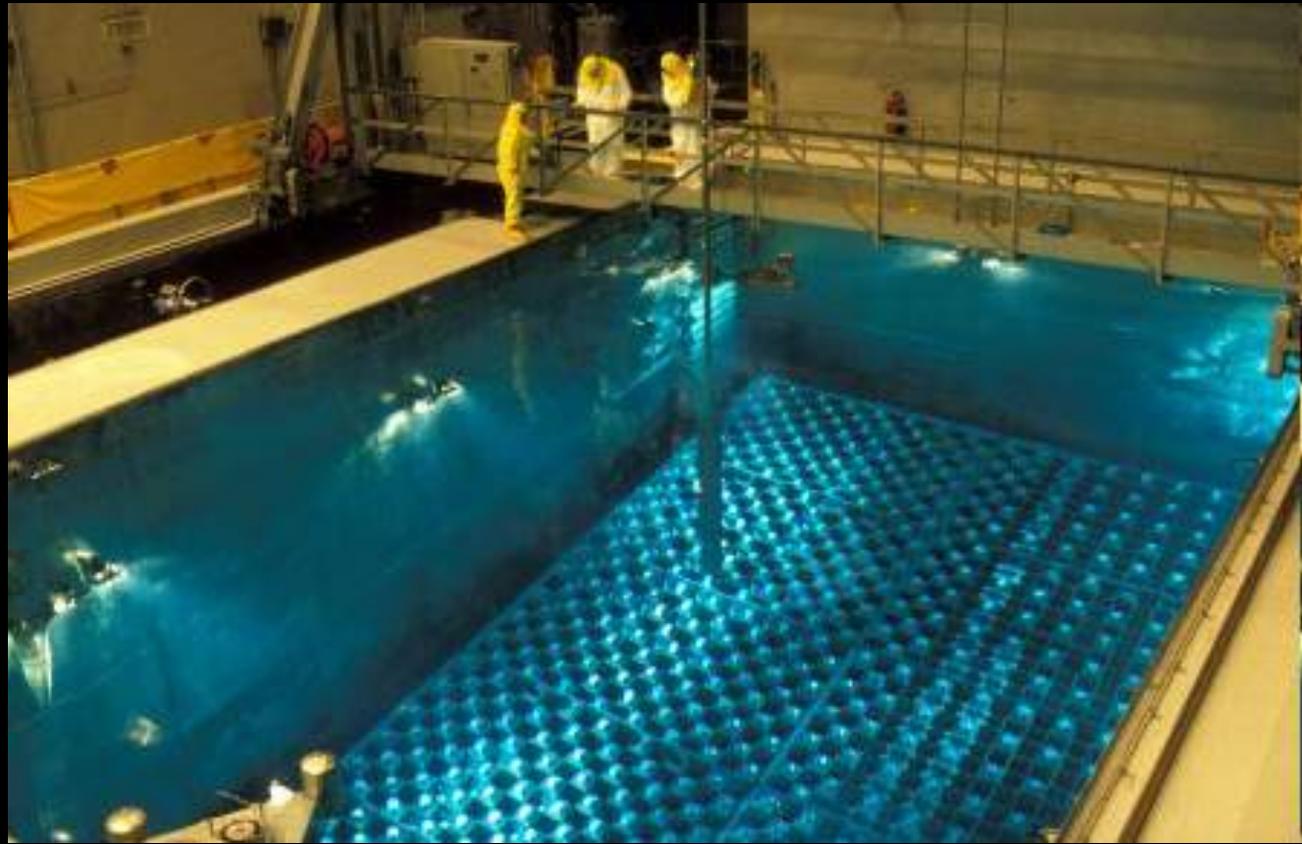
Core meltdown

- **Without cooling water, the zirconium alloy fuel rod cladding will overheat and react with water vapor**
 - **Potentially explosive hydrogen gas is released**
- **Soon afterward, fuel rod cladding will balloon and rupture and uranium fuel pellets will begin melt**
- **Within hours, the entire core will slump to the bottom of the reactor vessel, and eventually melt through to the containment floor**



Spent Fuel Pools

- Require AC power for cooling under normal circumstances
- Generate much less heat than reactor cores, so may go without forced cooling for days before fuel is damaged; but not as well protected as the reactor core
- A rapid loss of cooling water could cause a spent fuel fire, releasing a huge quantity of radioactivity
- With luck, this was prevented at Fukushima

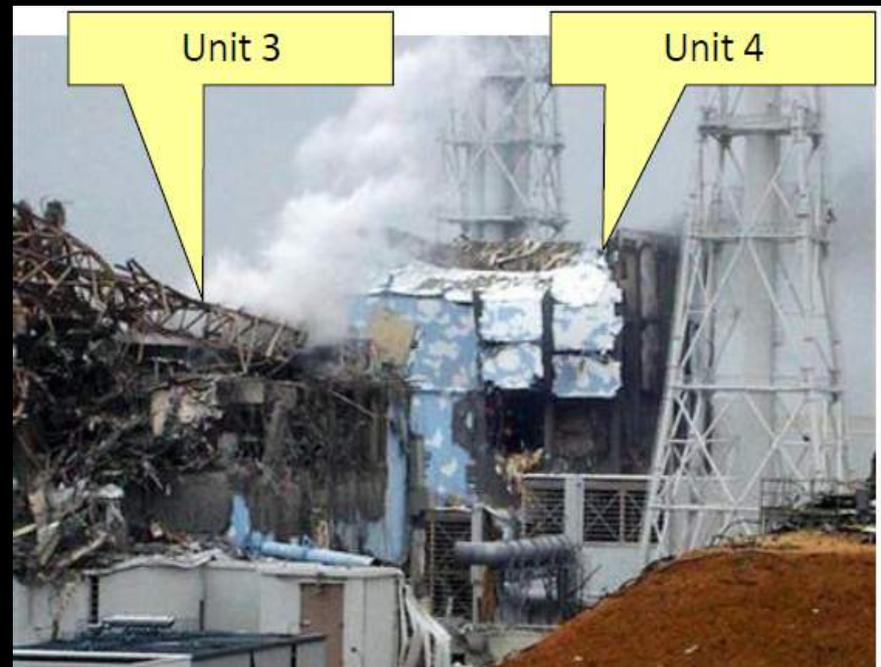
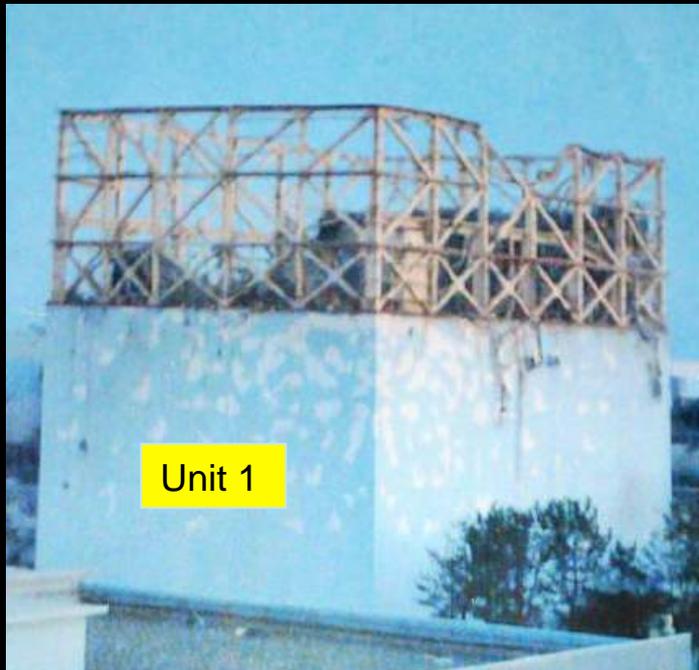




A mock spent fuel assembly after a fire test

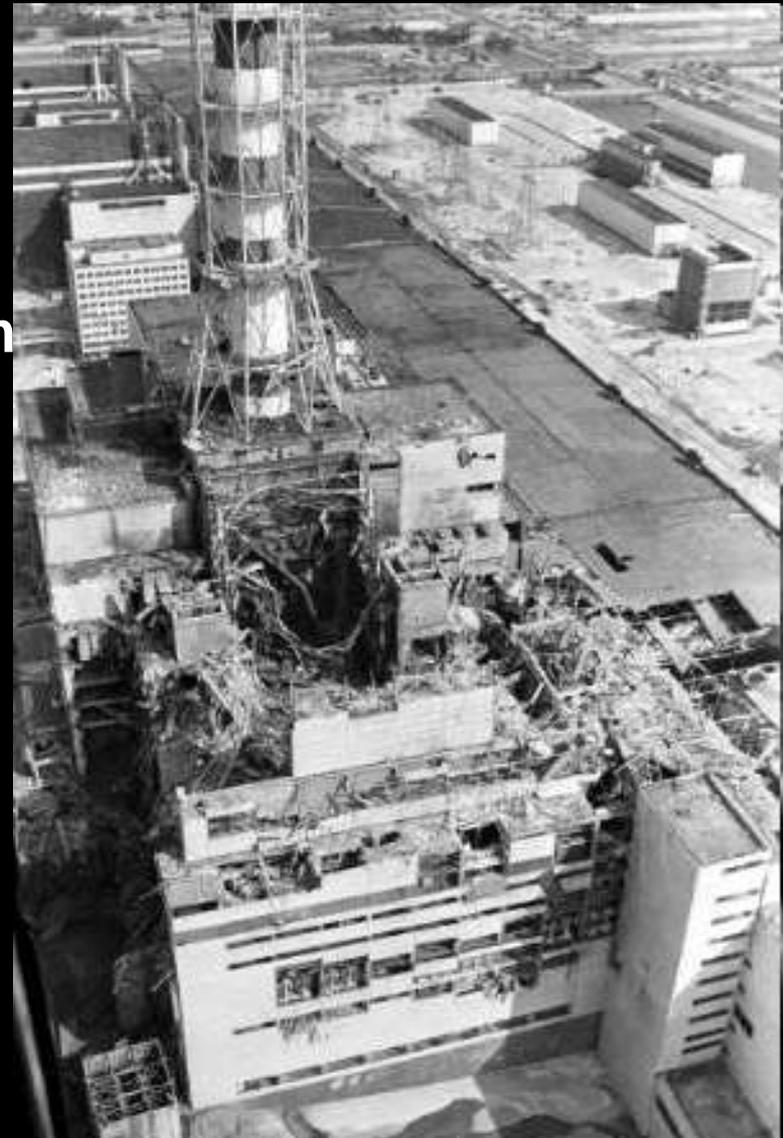
The Consequences

- 3 reactor core meltdowns
- 2 endangered spent fuel pools
- 3 hydrogen explosions that ruptured reactor buildings
- 3 overpressurized and leaking containments
- Massive releases of radiation into the air and water
- Ongoing environmental hazards at and around the site



Radiological Releases

- **Greatest concern:**
 - **Iodine-131 (8-day half-life):** primarily from reactor cores
 - **Cesium-137 (30-yr half-life):** from cores and spent fuel pools
- **Iodine-131 release from Chernobyl caused over 6,000 thyroid cancers in children**
- **Cesium-137 is responsible for the persistent radiation in the Chernobyl and Fukushima exclusion zones**



Threat to Americans

- **U.S. government advised Americans in Japan to evacuate up to 50 miles from site**
 - **Japanese evacuation zone was only 12 miles**
- **High-level concern that Americans may need to evacuate as far away as Tokyo**
- **Concern for contamination of milk supplies as far away as the West Coast of the continental U.S.**
- **The worst case did not come to pass, but U.S. authorities were very worried about it**

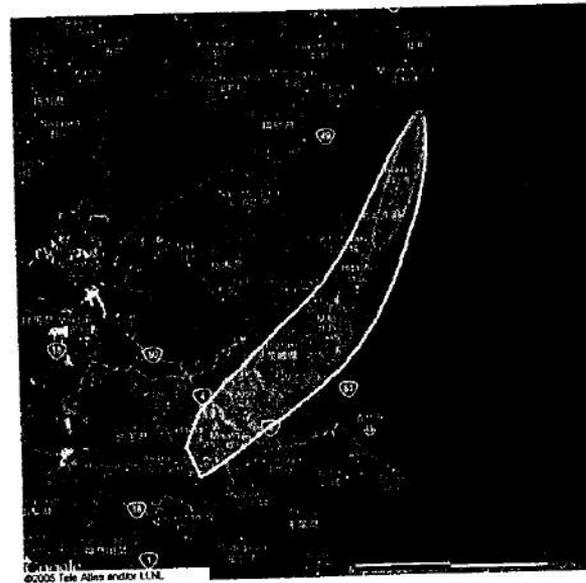
From March 25,
2011 Department of
Energy document

(Freedom of
Information Act
release to UCS)

Official Use Only

3. Plausible Severe Release

Release from 2 Spent Fuel Pools



The graphic indicates where the 96-hour total effective dose including plume passage exceeds 1 rem (yellow) and 5 rem (orange)

- In this hypothetical scenario, the US EPA Protective Action Guidelines for the total effective dose MAY be exceeded in Tokyo, as well as at locations closer to the release point.
- In this hypothetical scenario, the US EPA Protective Action Guidelines for both the adult and child thyroid dose will NOT be exceeded in Tokyo, but are exceeded at locations closer to the release point

Official Use Only

Atmospheric Releases

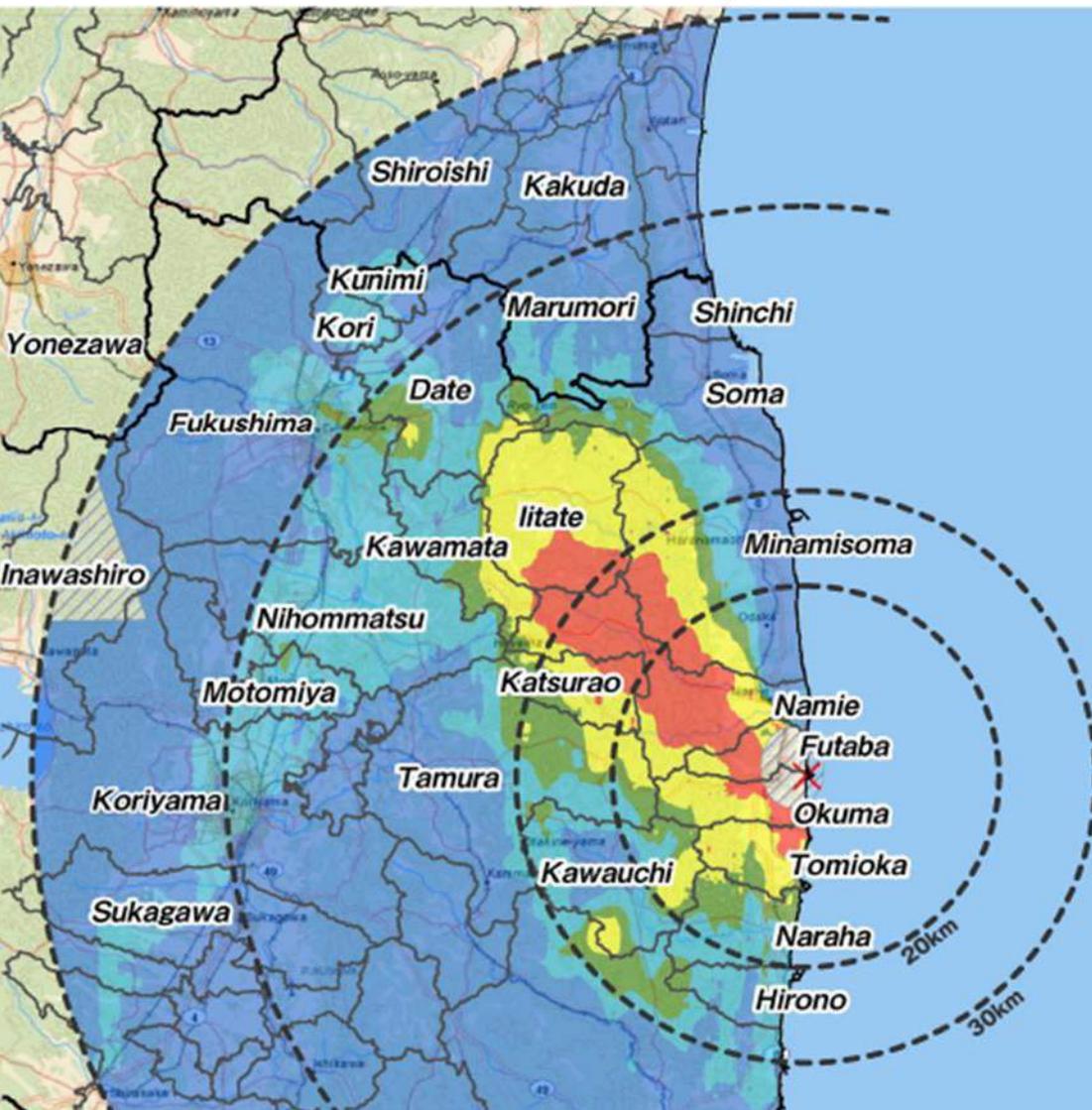
**~10-20% of
Chernobyl**



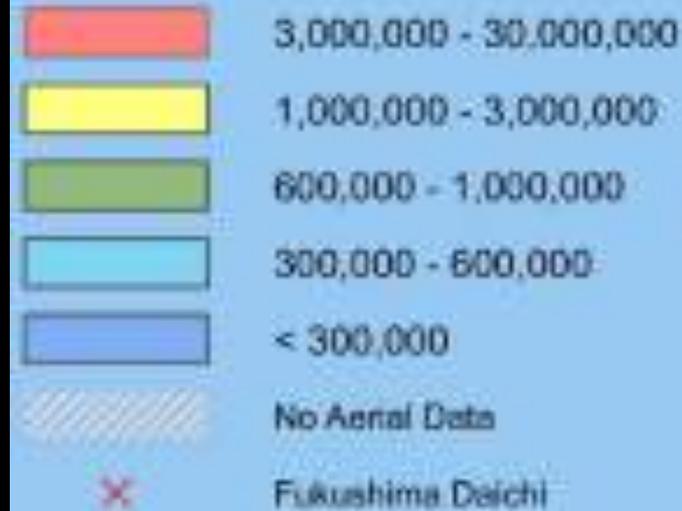
Cesium Contamination

Aerial Measuring Results

Joint US / Japan Survey Data



Total Cesium Deposition (Bq/m²)
Normalized to April 29, 2011



Aquatic Releases



HD

NHK WORLD

www.nhk.or.jp/nhkworld/

NHK WORLD

Ground Self-Defense Force video
March 18

NEWSLINE

The Present

- **“Cold shutdown” achieved but water must constantly be circulated through the damaged reactors and spent fuel pools, and then stored; site radiation dose is increasing**
- **Some radioactive water is being recycled and reused but some is leaking into the sea – “ice wall” proposed**
- **Decommissioning will take many decades and cost \$20 billion or more**



The human toll

- Compensation and remediation of contaminated areas may cost \$125 billion; over 130,000 still displaced
- Cancer deaths may number in the thousands, but most will be the result of radiation exposures not yet received

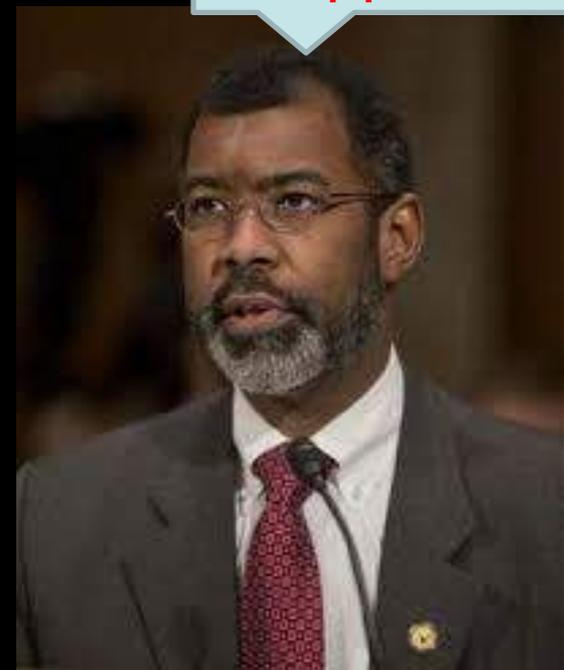


Source: Canadian Nuclear Safety Commission

Can it Happen Here?

- Yes, because *complacency* is as prevalent here as in Japan
- Safety requirements do not leave enough margin for error
- Rigorous emergency procedures to deal with severe events are only now being developed and may be inadequate

“I just don’t think it would happen.”



Former NRC commissioner Bill Magwood,
Senate testimony, March 15, 2012

How safe is safe enough?

- A more meaningful question: “How safe is safe enough?”
 - What are the most extreme events that regulators should require nuclear plants to be able to withstand?
 - What measures should regulators require to prevent or mitigate such events?
 - How large a radiological release should be considered “acceptable”?

U.S. vs. Japanese regulations

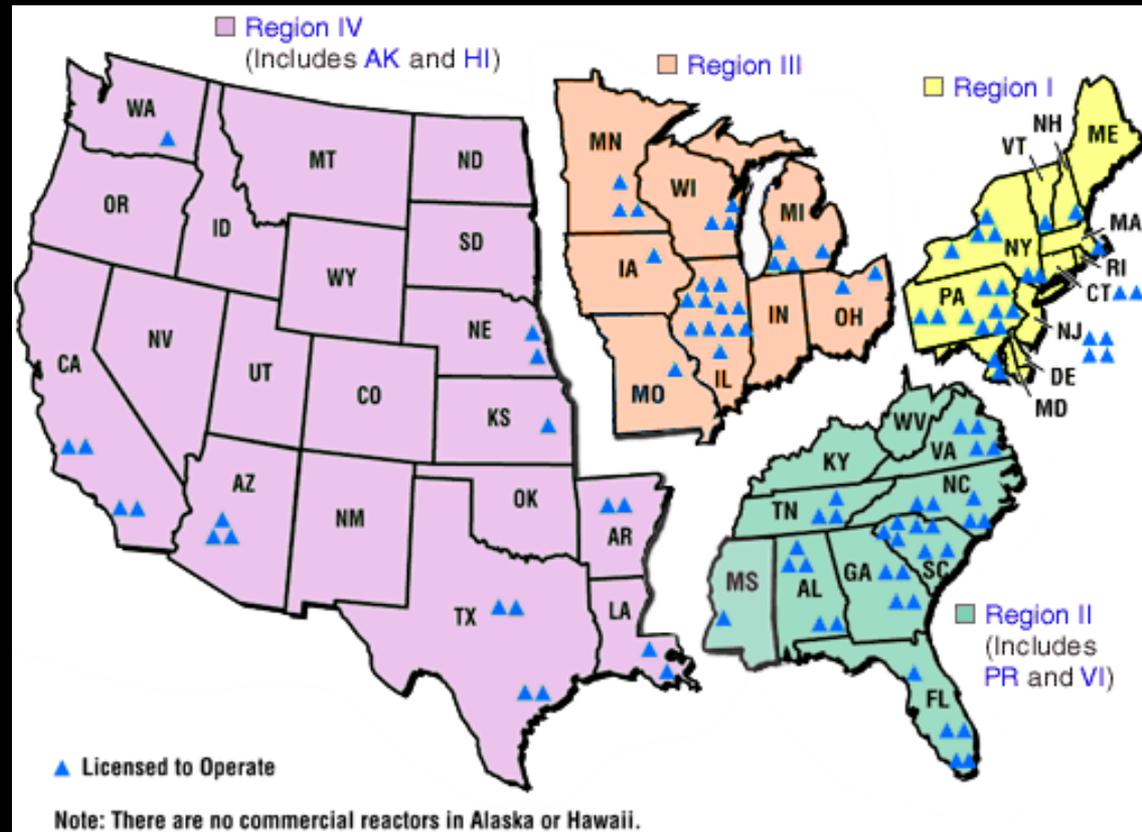
- “The accident ... was not of extremely low probability, i.e. was not ‘unthinkable’ or ‘unforeseen.’” NRC commissioner George Apostolakis, August 2, 2011.
- “... the Fukushima tragedy occurred in another country whose regulatory structure is quite different from that established in the U.S. ... I have long maintained this as an element of my decision making...” NRC commissioner William J. Ostendorff, *Nuclear Law Bulletin*, 2013.

but

- “...there should be no implication that the Fukushima accident and associated consequences could or would have been completely avoided assuming Japan had the same regulatory framework [as the U.S.] prior to the accident.” NRC staff report, November 2013

Safety of today's reactors

- 100 nuclear reactors licensed to operate today in U.S. (104 at beginning of 2013)
- Average risk of a nuclear reactor meltdown in the U.S. ~ 1% per year
- Containment failure chance up to 100%, depending on the containment type and accident





Ft. Calhoun, Nebraska

“The Oconee disaster would be no less severe (than the Japanese tsunami) on the [reactor] units. Everything on site would be destroyed or useless.” – internal NRC e-mail.



Oconee Nuclear Station (Seneca, South Carolina)

(Source: Duke Energy)

Threat from the air

- On 9/11, American Airlines Flight 11 passed over the Indian Point nuclear plant, 30 miles north of New York City
- al Qaeda planners decided not to attack nuclear plants because they thought the airspace was defended
- They were wrong then; they would still be wrong today!



Would we have been ready?

- **NRC and industry asserted soon after Fukushima that U.S. plants are better prepared than Japan was to manage such an event:**
 - **Severe Accident Management Guidelines (SAMGs)**
 - **Post-9/11 procedures to cope with aircraft attacks (B.5.b)**
- **However, these assertions do not stand up to scrutiny:**
 - **SAMGs are “voluntary” and not subject to regulation**
 - **B.5.b procedures were not designed to work during severe earthquakes or floods**
 - **Post-Fukushima inspections found many problems**

Near-Term Task Force

After Fukushima, the U.S. Nuclear Regulatory Commission convened a task force to evaluate whether safety upgrades were needed at U.S. nuclear plants

The task force found deficiencies in the current regulations and made 12 recommendations for improvements



Design-basis and severe accidents

- No nuclear reactor can be assumed to withstand an accident far greater than the “design-basis” accidents it was designed to withstand
- Regulators do not typically impose stringent requirements to deal with “severe” accidents because they assume they are so improbable
- But is the line between “design-basis” and “severe” accidents set in the right place, given uncertainties? How safe is safe enough?

Key NNTF Recommendations

- **#1: Establish a “logical, systematic and coherent regulatory framework for adequate protection that appropriately balances defense-in-depth and risk considerations”**
- **#2: Require re-evaluation and upgrading of design-basis seismic and flooding hazards**
- **#4: Strengthen station blackout mitigation capability for design-basis and beyond-design-basis external events**
- **#5: Require “reliable” hardened vents for Mark I and II BWRs**

Key Recommendations

- **#7: Enhance spent fuel pool mitigation and instrumentation**
- **#8: Strengthen and integrate onsite emergency response capabilities (eg. SAMGs and B.5.b)**
- **Additional issues (post NTTF)**
 - **Emergency planning zone size (evacuation and KI distribution)**
 - **Filtered and/or severe accident capable vents**
 - **Expedited transfer of spent fuel to dry casks**

NRC near-term actions

- **Re-examine risks of earthquakes and flooding (#2)**
- **Require additional emergency equipment that can be used during extended losses of alternating current power (#4)**
- **Require “reliable” and “severe accident capable” vents for Mark I and II BWRs (#5)**
- **Require reliable spent fuel pool instrumentation (#7)**

Actions NRC has postponed or rejected

- Revising the regulatory framework (#1) **NO**
- Requiring filters for BWR containment vents
DECISION POSTPONED
- Expanding emergency evacuation planning zones beyond 10 miles **NO**
 - Japan has done it – why not the U.S.?
- Requiring accelerated transfer of spent fuel from pools to safer dry casks **NO**
 - Defense-in-depth measure to reduce fire impacts

“FLEX” concept

- **The U.S. nuclear industry proposed “FLEX” as a panacea for the weaknesses revealed by Fukushima**
- **Involves deploying off-the-shelf emergency equipment for supplying power and cooling at multiple locations, at and away from reactor sites**
 - **Charles Pardee, (then of) Exelon: “It’s cheaper to buy three pumps than one pump and a heckuva big building ...”**
- **Two “regional response centers” in Memphis and Phoenix: goal is to supply any site within 24 hours**
- **FLEX’s ultimate effectiveness will depend on**
 - **The survivability of the equipment**
 - **The feasibility of the strategies under real conditions**

“Stakeholder” input

The Nuclear Regulatory Commission has endorsed the FLEX approach but acknowledges that

“Stakeholder input influenced the NRC staff to pursue a more performance-based approach [e.g. FLEX] to improve the safety of operating power reactors than envisioned in NTTF Recommendation 4.2 ...” – boilerplate language in NRC interim Safety Evaluation Reports

The problem with FLEX

- There is no question that a flexible response is desirable, given the many different ways an accident can occur
- However, the industry is using “flexibility” as a justification for avoiding the need to meet specific performance standards
- As a result, the current FLEX rules remain vague and do not “provide sufficient guidance on the evaluation of the feasibility and reliability of the manual actions” needed, according to the NRC’s Advisory Committee on Reactor Safeguards



“FLEX” portable pumps

Columbia Generating Station FLEX plan

- CGS FLEX plan (revised 8/14) to cope with an extended loss of alternating current power while operating (note: DC power and distribution assumed available)
 - Stage 1: Use RCIC and depressurize reactor pressure vessel
 - Stage 2:
 - Continue to use RCIC (bypass RCIC trips)
 - Ready FLEX pumps for injection into RPV in case of RCIC failure
 - Use FLEX to recharge batteries within 10 hours
 - Vent containment within 6 hours to reduce wetwell temperature;
 - Use FLEX pump within 12 hours to maintain spent fuel pool water level as pool boils; allow overflow to “cascade” into wetwell
 - Stage 3: Continue indefinitely until help from Regional Response Center in Phoenix arrives (36 hours assumed)

CGS scorecard

- FLEX and reliable hardened vent implementation
 - Energy Northwest was required to implement FLEX by spring 2015
 - All Mark I/II BWRs are required to have severe accident capable reliable hardened wetwell vents by June 2018 at the latest
- Energy Northwest initially proposed to credit its existing sheet metal ductwork for satisfying the FLEX venting requirement
 - Even the NRC found that request too hard to swallow
- Energy Northwest has requested a delay in FLEX implementation until hardened vent is installed in spring 2017

CGS scorecard

- Flooding hazard reevaluation: was due in March 2014
 - Energy Northwest, like many other plants, received an extension pending receipt of an Army Corps of Engineers analysis of dam flooding hazards; yet claims that it is a “dry” site that does not have to cope with flooding
- Seismic hazard: will perform “expedited” seismic safety analysis
 - Like most other plants in the U.S., the seismic risk is greater than the design basis

Will new reactors be safer?

- **Westinghouse claims that the passive AP1000 plant would have been able to withstand Fukushima**
 - Can cope with 72-hour station blackout in *design-basis* accidents – but what about more severe accidents?
 - The NRC gave the AP1000 a pass by exempting it from the requirement for an on-site capability to cope with an extended station blackout
- **The AP1000 does not have features to protect against severe accidents such as**
 - Highly reliable active backup systems
 - Highly reliable hydrogen control systems
 - Containment that can withstand high pressures
- **As part of the design certification, Westinghouse calculated that these were not cost-effective**

Small modular reactors

- **Small modular reactors are currently defined as**
 - **< 300 MWe**
 - **Small enough to be manufactured in factories and shipped to generating stations to meet incremental demand growth**
- **The SMR is an old concept that has repeatedly been rebranded; vendors claim they are**
 - **More “affordable” than conventional reactors**
 - **More suitable for distributed generation**
 - **Safer than current generation reactors (especially after Fukushima)**

SMR economics

- major overnight capital cost (OCC) disadvantage (in \$/kW) compared to larger reactors ($n = 0.62$):

$$OCC_{SMR} = OCC_{LARGE} \times \left(\frac{\text{size}_{SMR}}{\text{size}_{LARGE}} \right)^{n-1}$$

- Westinghouse SMR: $OCC_{SMR} = 1.83 OCC_{AP1000}$
- Vendors assert that the economies of scale penalty can be offset by factors such as economies of mass production and reduced upfront financing, but this is unproven
- Analytical studies have found that at best, these factors can make SMRs roughly competitive with large nuclear plants
- Experience to date with modular fabrication of nuclear-grade parts for the AP1000 has not been good (Lake Charles, LA facility)

SMR O&M costs

- Operations and maintenance (O&M) costs, other than fuel, are also influenced by economies of scale
 - Compare the now-shut Kewaunee (1.3 workers per MWe) to Point Beach (0.67 per MWe)
- To improve the economics, SMR vendors are seeking regulatory relief through regulatory relief from requirements including operator staffing, security and emergency planning to obtain cost savings relative to large plants

“Catch-22”

- Cost reductions associated with SMR mass production would not become apparent until hundreds of units are manufactured
- But until those reductions are realized, SMRs will be too expensive for utilities to buy without significant incentives
- To date, DOE has offered only up to \$452 million in matching grants to SMR projects for “licensing technical support”
- Secretary of Energy Advisory Board (SEAB): “If the U.S. is to create a potential SMR market for U.S. vendors, it will need to do something to help out with such costs”
 - Funding demonstration plants on U.S. government sites
 - Cost sharing beyond design certification
 - Loan guarantees
 - Power purchase contracts
- DOE hopes to boost the domestic industry by filling its order book internationally: China, Kenya, Nigeria, Bangladesh ...

Safety and SMRs

- **Although passive heat removal for smaller reactors may be easier, benefits are not automatic**
 - **Fukushima Daiichi Unit 1 was 460 megawatts-electric**
- **Far more important are the criteria governing SMR design, licensing and operation, including severe accident and sabotage resistance**
 - **a key issue is application of post-Fukushima requirements**
- **Weakening regulatory requirements for SMRs could erode safety improvements provided by design**
 - **can SMRs be both safer and more cost competitive than large reactors?**

A new safety regime

- **Regulators should *require***
 - **New regulatory analysis guidelines**
 - Larger margins to safety limits
 - Greater defense-in-depth
 - Appropriate values for human life and the impacts of long-term land contamination
 - **A comprehensive and systematic review of all existing plants, including “stress tests”**
 - **Implementation of all cost-beneficial safety enhancements**
- **“Hardened core” like the French approach?**

It CAN happen here

- **Fukushima was not a “Japanese” nuclear accident; it was a nuclear accident that happened to occur in Japan**
- **The nuclear industry, regulators and politicians must abandon the “it can’t happen here” mindset, and apply *all* the lessons of Fukushima to nuclear power plants here at home**
- **Otherwise, nuclear power’s credibility may not survive another serious accident or terrorist attack**

Questions?

For more information, please visit

www.fukushimastory.com

Thank you for your attention!