Proposals for Reducing the Danger of Spent Fuel Pool Fires: The U.S. Nuclear Regulatory Commission's (NRC's) Response

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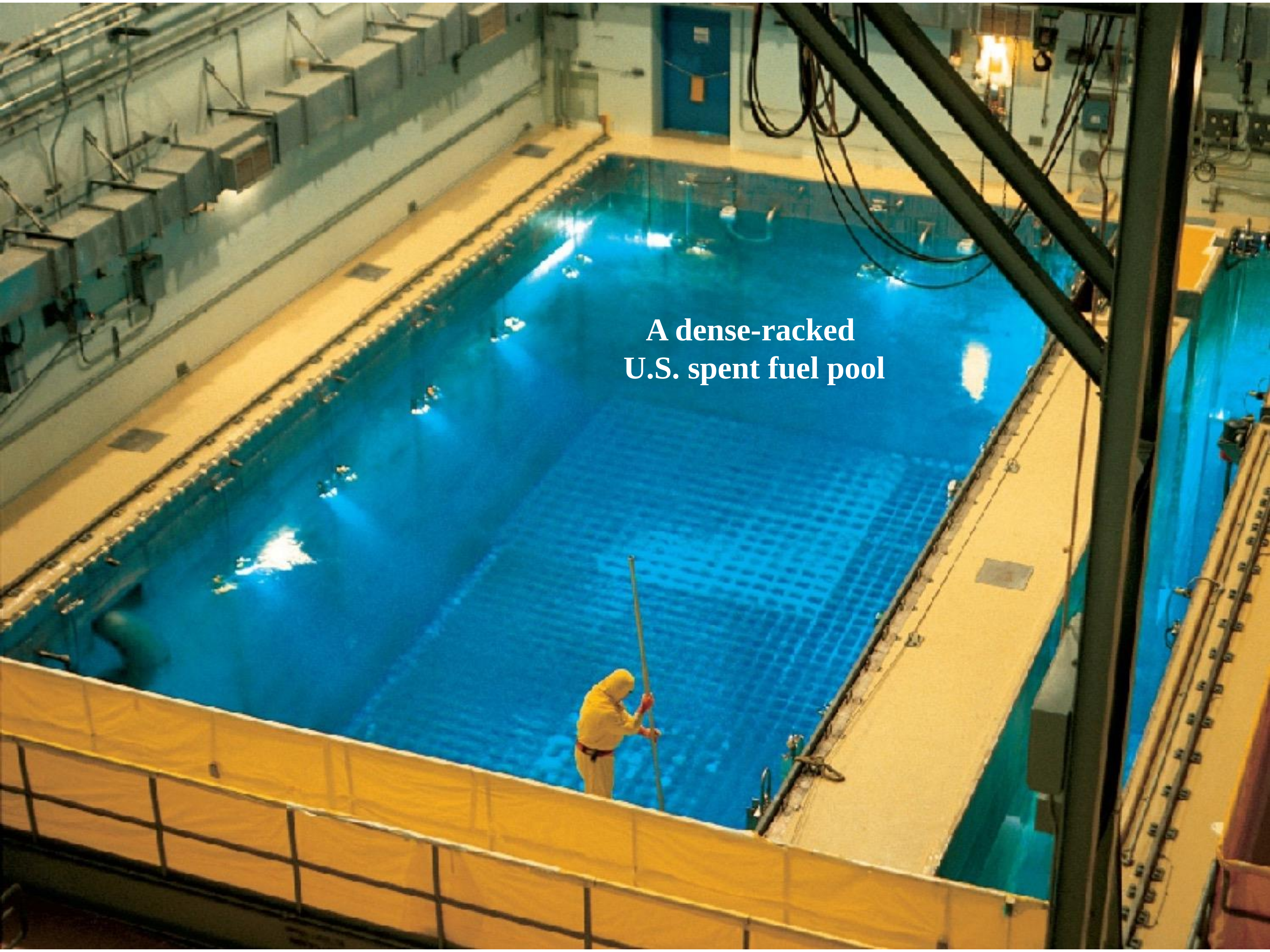
Tokyo, 22 November 2016

Based on a paper, "Reducing the Danger from Fires in Spent Fuel Pools," written with Michael Schoeppner, published in *Science & Global Security*, 16 Nov. 2016

That paper builds on a recent National Academy of Sciences report,

Lessons learned from the Fukushima nuclear-accident for improving safety and security of U.S. nuclear plants, Phase 2 (2015)

http://www.nap.edu/catalog/21874/lessons-learned-from-the-fukushima-nuclear-accident-for-improving-safety-and-security-of-us-nuclear-plants


A dense-racked
U.S. spent fuel pool

Radioactive releases from spent fuel pool fires potentially much larger than from reactor accidents.

Land contamination by 30-year half-life Cesium-137 dominates long-term population radiation dose and cancer risk and can force long-term or permanent evacuation of large areas.

700 PBq* of Cs-137 in melted cores of Fukushima 1-3 but their containment structures released only 1 to 3 percent to atmosphere.

Spent fuel pool #4 contained 900 PBq but, after hydrogen explosion, it was open to the atmosphere and, in a spent fuel fire, ~90% would have been released to the atmosphere.

*1 Becquerel (Bq) = 1 disintegration per second

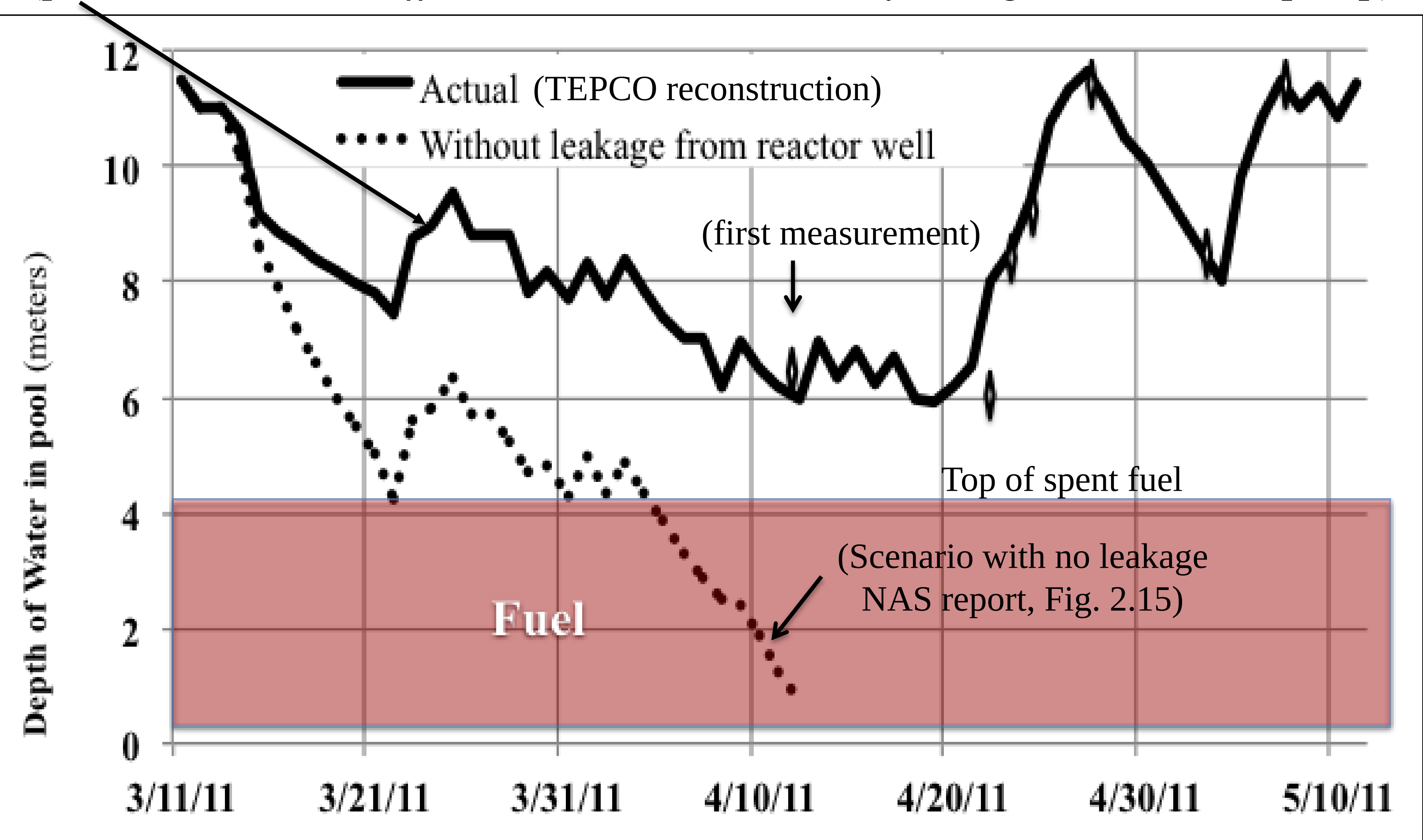
1 MBq = million disintegrations per second

1 PBq = 1000-trillion disintegrations per second

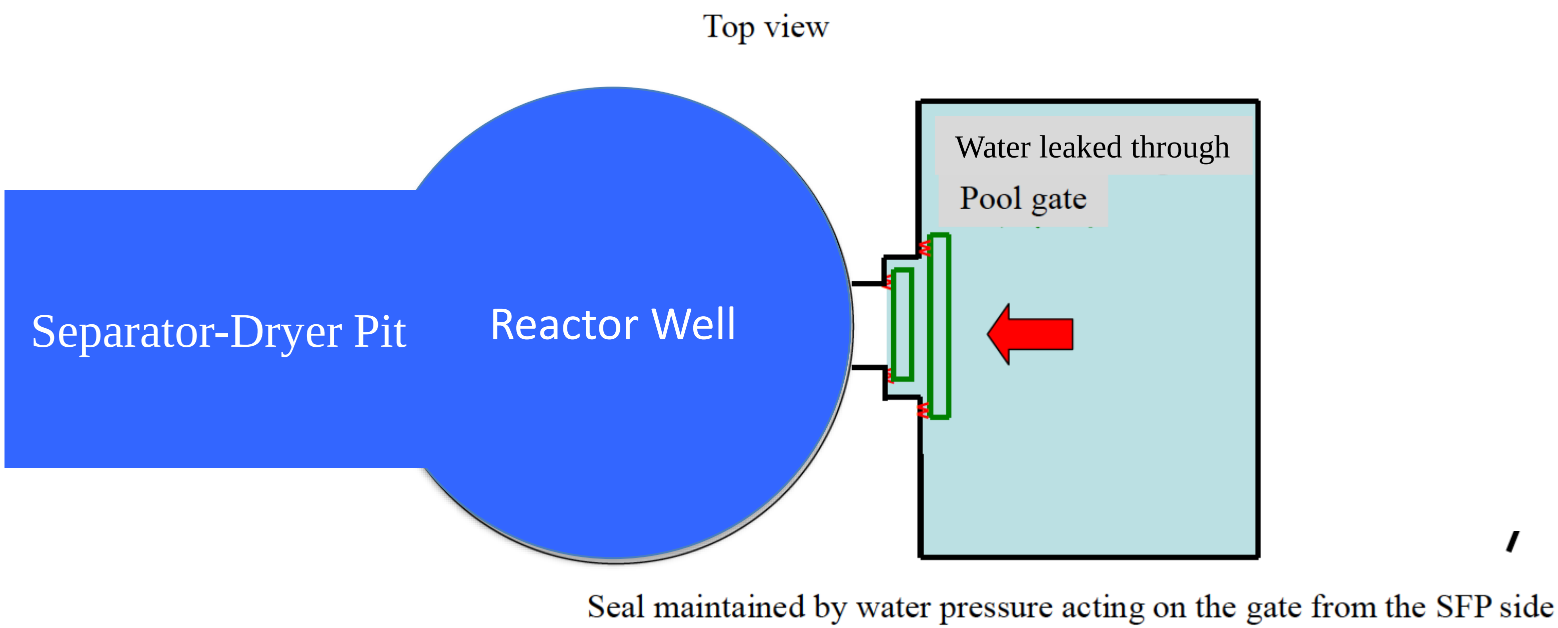
Reactor Building #4, 1 May 2011

Fukushima Spent Fuel Pool #4 saved from dryout because of leakage *into* the pool from the adjacent reactor pit

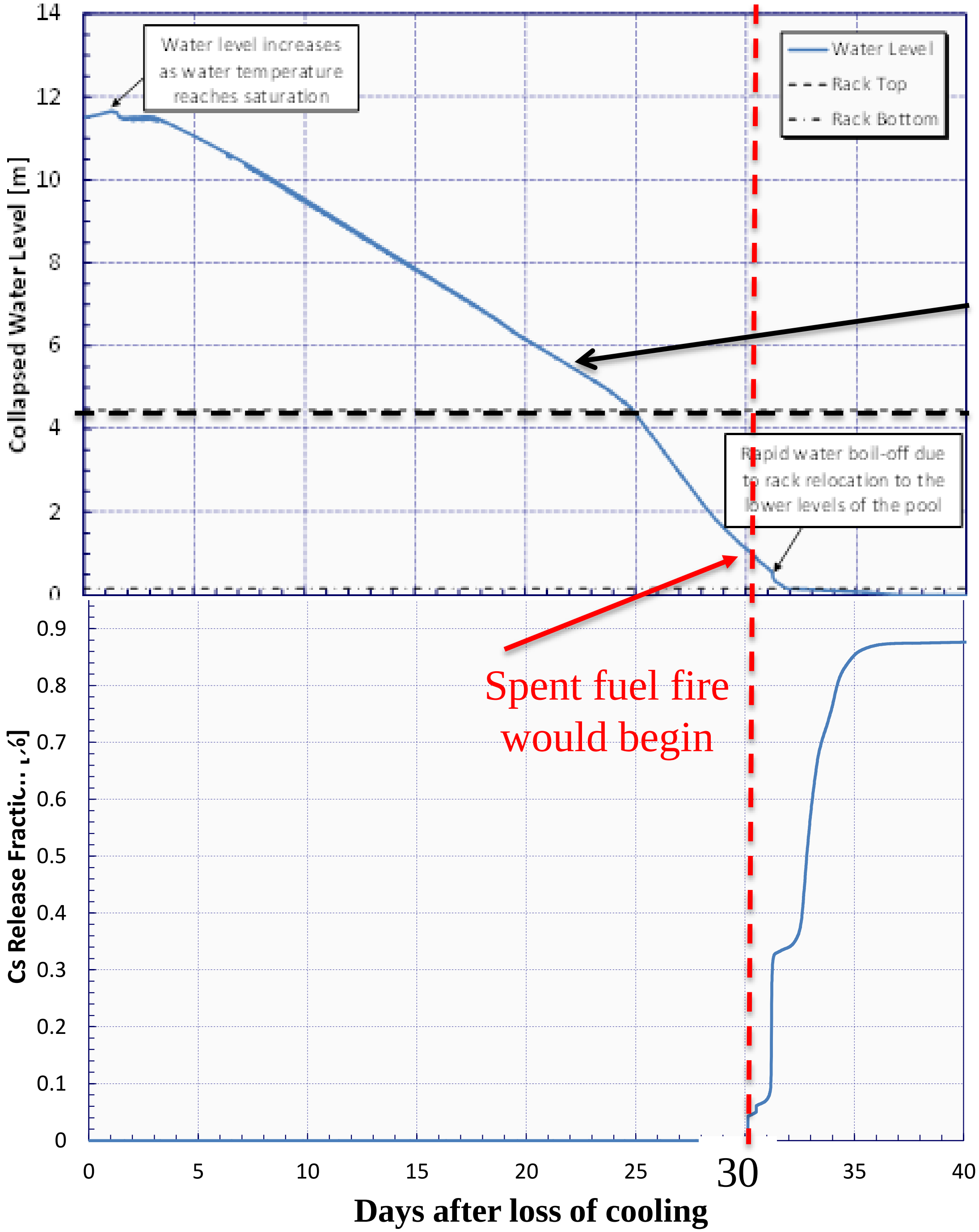
(peaks are due to *insufficient* additions of water by the "giraffe" cement pump)



Source of water that kept the spent fuel in pool #4 covered



(TEPCO, 2012 Report, Attachment 9-5, Figure 3)



If no water added, would have had fire in 30 days. If pool leaked, much sooner.

Water level with dryout.

Top of the fuel

Cesium release fraction

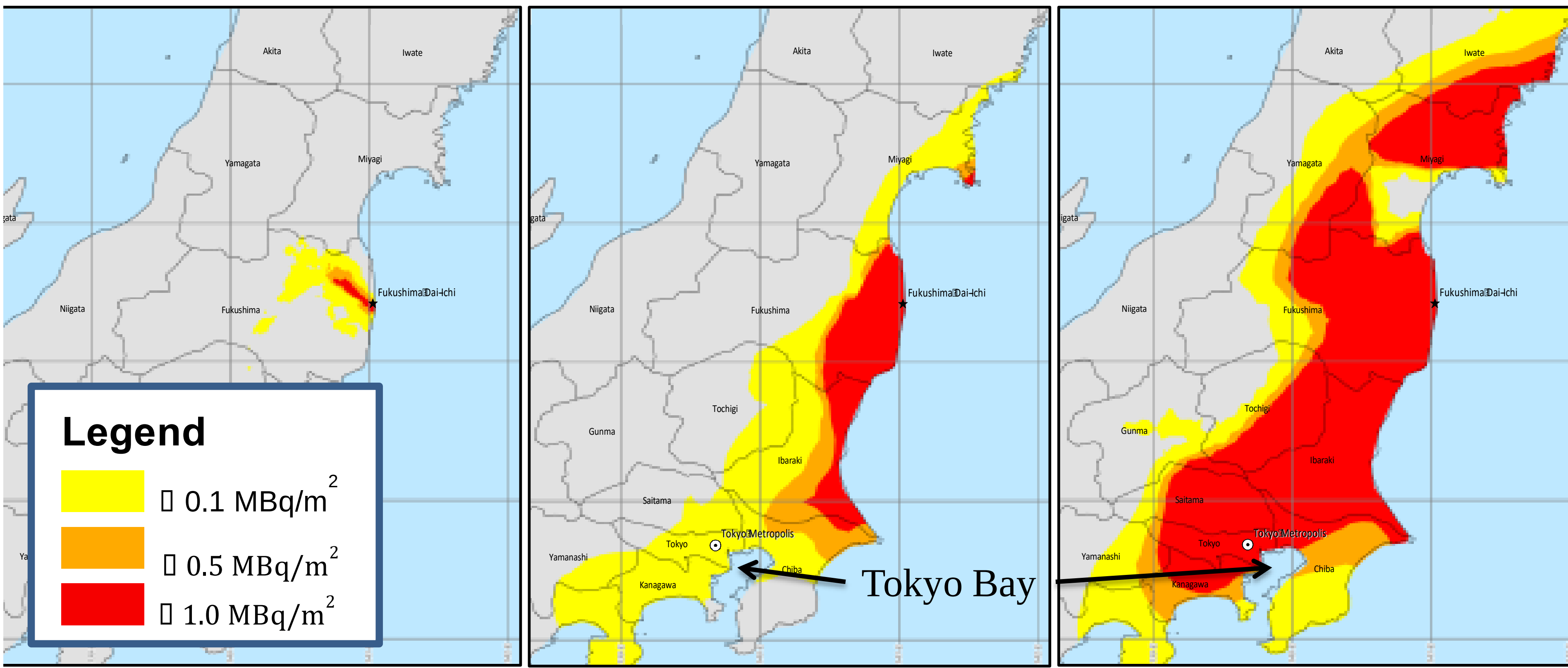
(~88 % after 5 days)

(*Fukushima Daiichi Accident Study, Status as of April 2012*, Sandia, 2012)

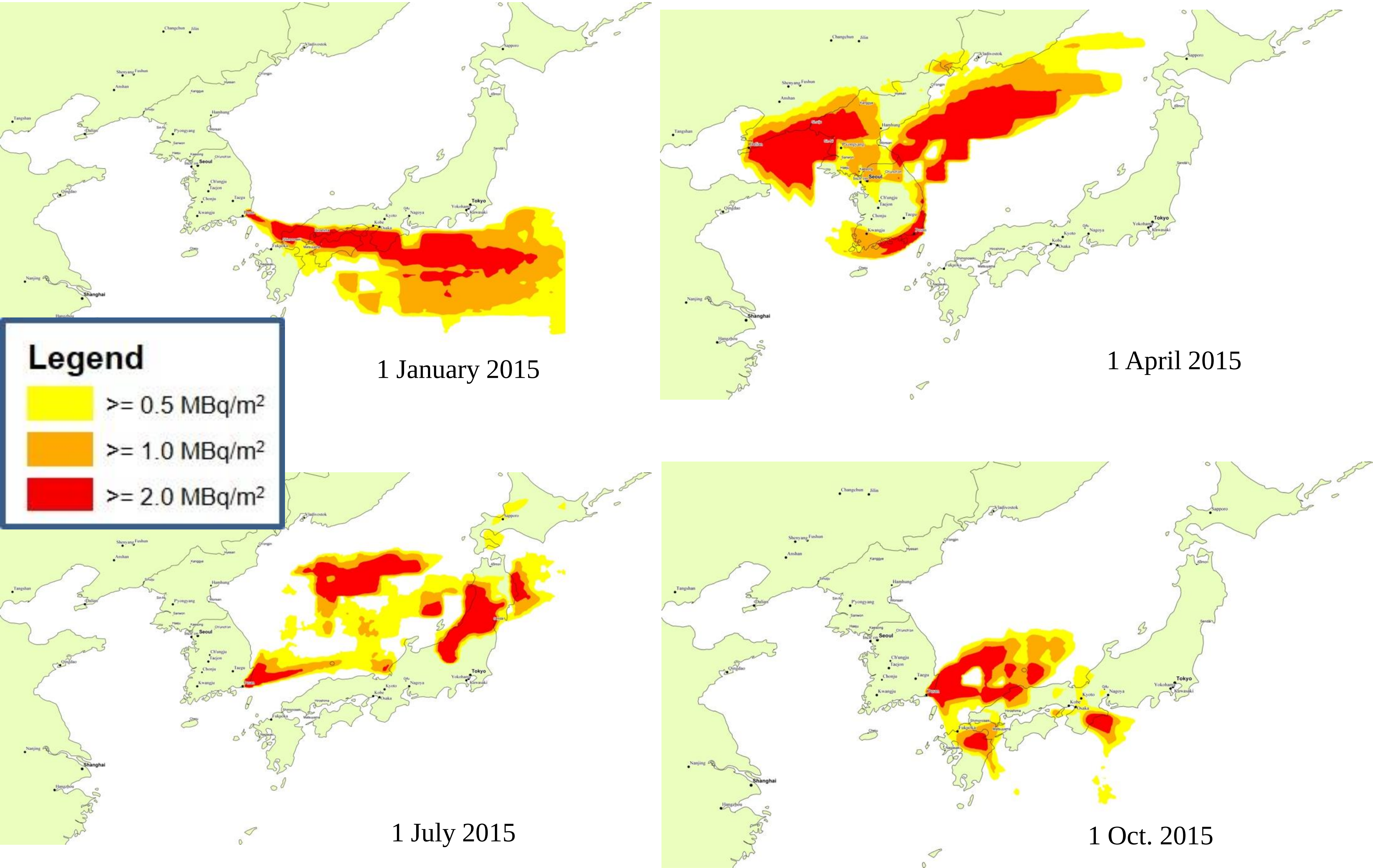
Fukushima population evacuated if $\geq$ 1 MBq/m^2 Cs-137 contamination

Hypothetical fire in spent fuel pool #4
HYSPLIT calculations, historical weather

Actual Fukushima accident (3/15/2011)	**Wind off shore**(4/9/2011)	**Wind onto land** (3/19/2011)
Evacuated: 88,000	Evacuated: 1,600,000	Evacuated: 35,000,000
from 1,100 km^2	from 4,300 km^2	from 31,000 km^2



In East Asia, a spent fuel pool fire in one country could have impacts in another. Example: Kori 3 in the ROK



U.S. Nuclear Regulatory Commission (NRC) and Spent Fuel Fires

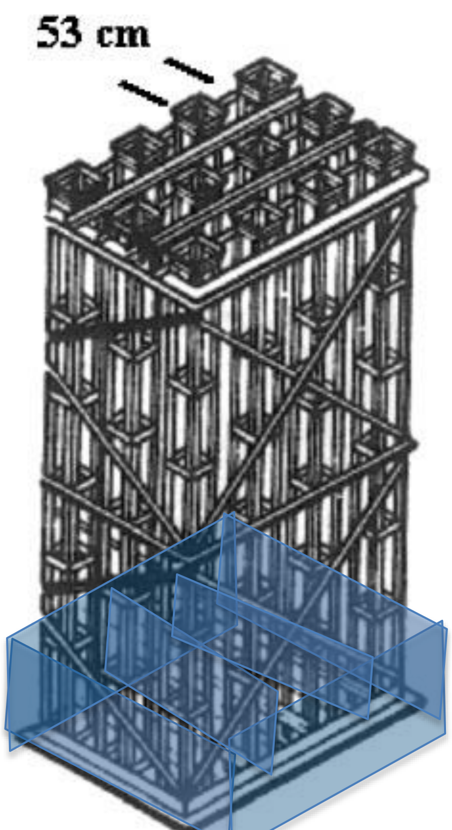
U.S. spent fuel pools originally designed to hold fuel for a few years until it could be shipped to a reprocessing plant.

In 1982, U.S. policy changed to direct disposal.

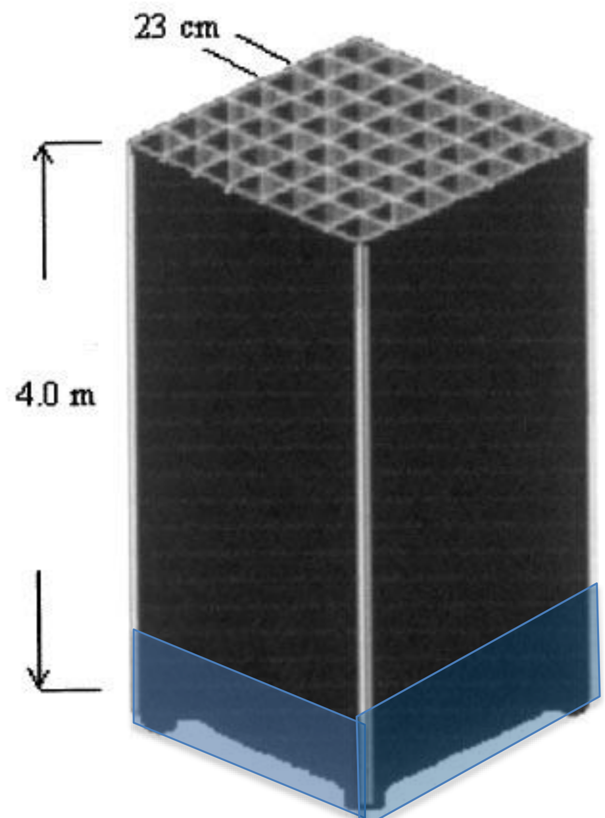
Utilities decided to go from low-density open racking to high-density racking.

Neutron-absorbing partitions added around each assembly to prevent chain reaction.

National lab experts suggested staying with low-density racking in case of loss of coolant but ***NRC decided probability too low to be of concern***.



Low density, air-cooling possible



High density, air-cooling not possible – especially if partial drainage and bottom of racks covered with water.

2003 Proposal to transfer to dry-cask storage after 5 years

Proposal: Transfer of spent fuel to dry casks after 5 years pool cooling and return to open-rack storage.*

Congress requested a National Academy of Sciences (NAS) review. NAS report recommended consideration within the context of terrorism vulnerability assessments (2006).** NRC did nothing.

After Fukushima, U.S. Nuclear Regulatory Commission (NRC) asked its staff to study the proposal further.

Staff decided to do a cost-benefit analysis.

* Robert Alvarez, Jan Beyea, Klaus Janberg, **Jungmin Kang**, Ed Lyman, Allison Macfarlane, Gordon Thompson & **Frank von Hippel**, "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States," *Science & Global Security*, Vol. 11 (2003) pp. 1-51.

** *Safety and Security of Commercial Spent Nuclear Fuel Storage* (National Academy Press, 2006). There also was a classified report in 2004.

When a dense-packed spent fuel pool is full in the U.S., spent fuel cooled 20-30 years is moved to dry-cask air-cooled storage

(Connecticut Yankee Nuclear Power Plant, historical)

Hydrogen explosion less probable if spent fuel transferred to dry cask storage after 5 years

Hydrogen is produced when the zirconium cladding of the spent fuel is uncovered and becomes hot in the presence of water vapor:

H_2O (vapor) + Zr → H_2 + ZrO.

NRC staff found less hydrogen and explosion much less likely with low-density pool storage.

If building stays intact, much less Cs-137 released to atmosphere from an accident.

NRC cost-benefit analysis

NRC staff estimated average release of ***1600 PBq from fire in a high-density pool with a hydrogen explosion and 20 PBq from a low-density pool without a hydrogen explosion: 80 times less!***

Cost of extra casks to go to low-density racking ~ $50 million per pool

Estimated average economic costs for a high-density pool fire in the United States ~ $700 billion and probability of accident at 1/10,000 per pool during remaining licensed life).

Possibility of terrorism ignored.

($700 billion)/10,000 ~ $70 million probability-weighted benefit/pool.

Underestimate because NRC assumed:

1. ***Decontamination would take less than a year***
2. ***Population relocation dose threshold 3x higher than Fukushima, Chernobyl and U.S. Environmental Protection Agency guidance…***

Corrected benefits would be significantly greater than costs.

But NRC introduced assumptions to reduce the benefits

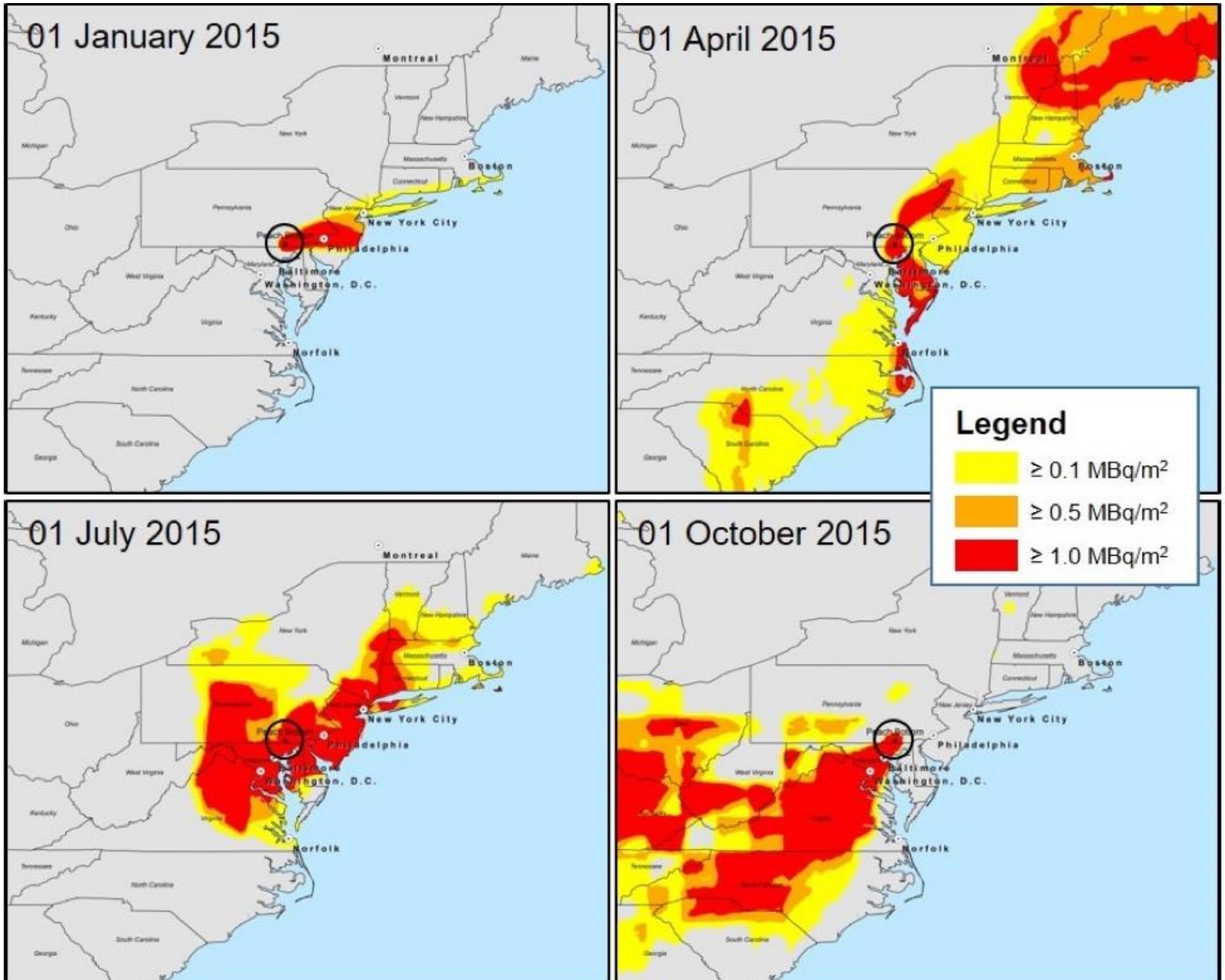
1. Accident consequences beyond 80 km excluded
2. 1995 estimate of value of a life lost to cancer used instead of updated value 2.5 times larger.
3. Assumed other nuclear power plants not shut down….

Concluded:

1. Benefits ~ 10% of costs and
2. Risks not significant.
3. Therefore no need to go to low-density pools.

Evacuation areas for release of 1600 PBq Cs-137 from spent fuel fire in a dense-packed pool at the U.S. Peach Bottom NPP

(historical weather, small circles: NRC's 80-kilometer radius cutoff)



Huge areas and populations would be have to be evacuated for many years in case of a 1600 PBq Cs-137 release

U.S. Environmental Protection Administration guidance for relocation is projected unshielded dose of 0.04 Sieverts in five years (~1 MBq/m^2). For that dose, additional cancer risk is about 0.4%.

Average evacuated area	**100,000 km^2**
	[Fukushima ~ 1,000 km^2]
Average evacuated Population for spent fuel fire at U.S. Peach Bottom NPP	**15.3 million**
	[Fukushima ~ 0.1 million]

Nuclear regulation is political

1. ***Aggressive regulators cannot be confirmed to the NRC today because of influence of industry on Senate, which must confirm the President's nominations***.
2. ***Congress can use its control of the NRC's budget when the industry complains about too aggressive regulation***. In 1998, Senator Domenici, chairman of Senate Appropriations subcommittee, threatened to cut the NRC's budget by one third because of industry complaints and the NRC became much less aggressive.*

*Pete Domenici, *A Brighter Tomorrow: Fulfilling the Promise of Nuclear Energy* (2004), "The NRC's Day of Reckoning."

My recommendations

1. Regulatory objective should be to minimize danger of large releases.

NRC estimates probability of a large release in the lifetime of current U.S. reactor fleet as between 0.14 and 6%, not including terrorism.

2. Transfer older spent fuel to dry cask storage would cost ~$4 billion in U.S.

~ $1 billion in Japan because of smaller number of pools.

Much less costly, much faster to implement and much safer than spent fuel reprocessing.

Better than paying for the consequences of an accident that would displace millions of people.