Nautilus Institute Working Group Meeting:
Spent Fuel, Radiological Risk, Deep Borehole, etc.,
Beijing, 28-30 May 2013

"Assessment of SNF Radiological Risk: Review of Methodology, and Application to a Case Study from USA"

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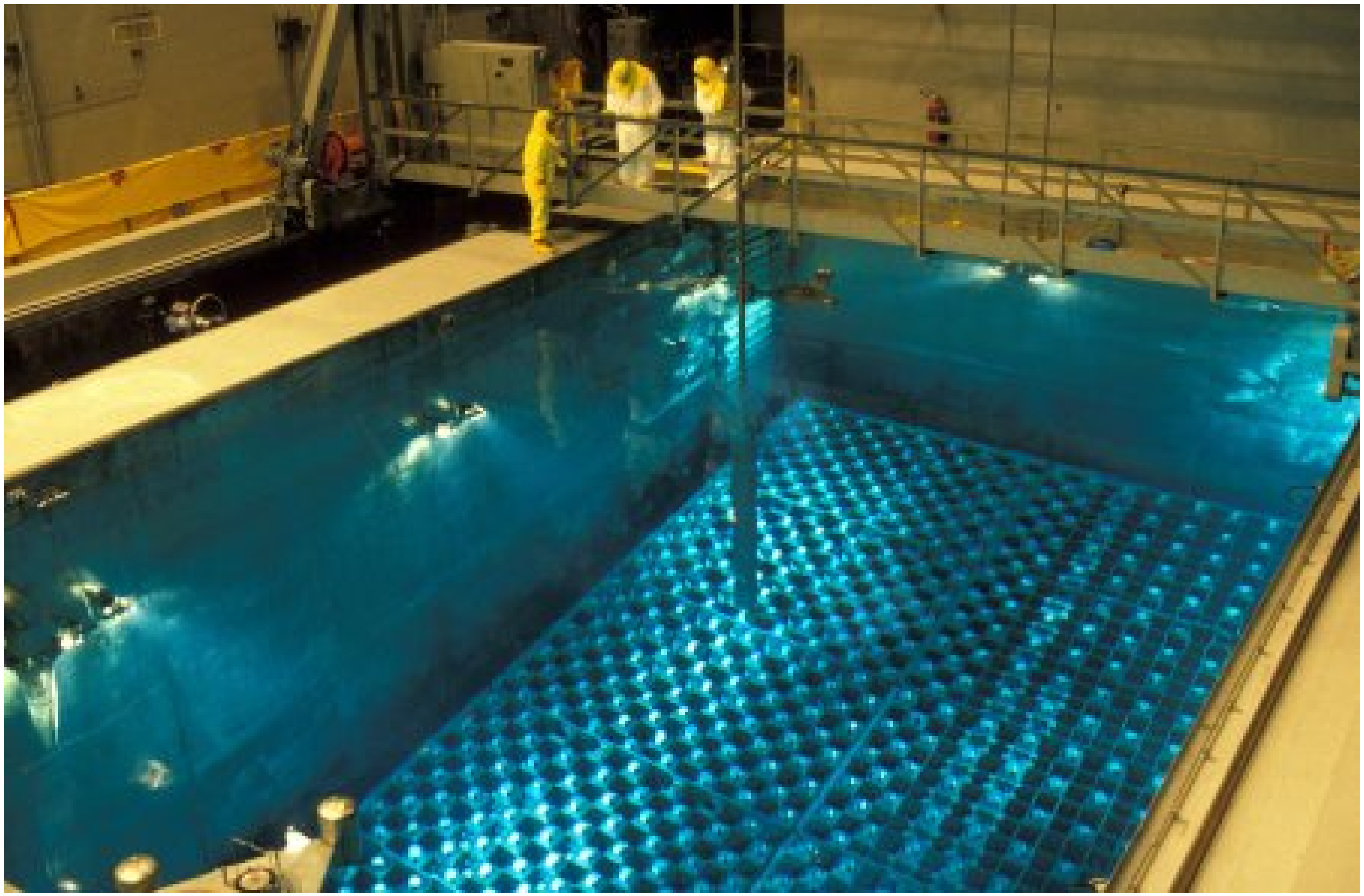
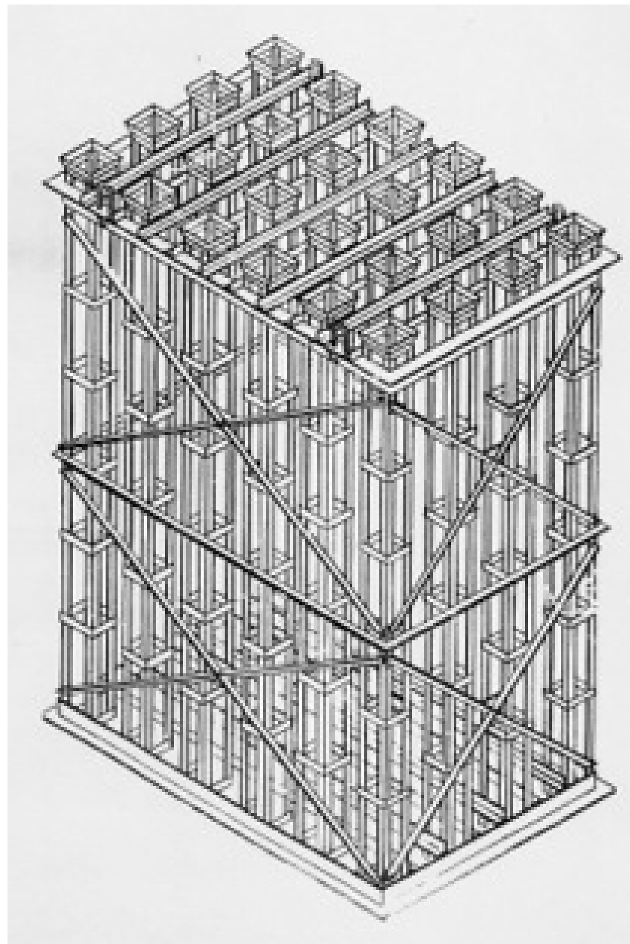
Steps in Assessing SNF Radiological Risk

- **Step 1: Specify the system**
- **Step 2: Characterize SNF**
- **Step 3: Assess release potential**
- **Step 4: Estimate plume behavior**
- **Step 5: Characterize downwind assets**
- **Step 6: Assess harm to downwind assets**
- **Step 7: Assess collateral implications**

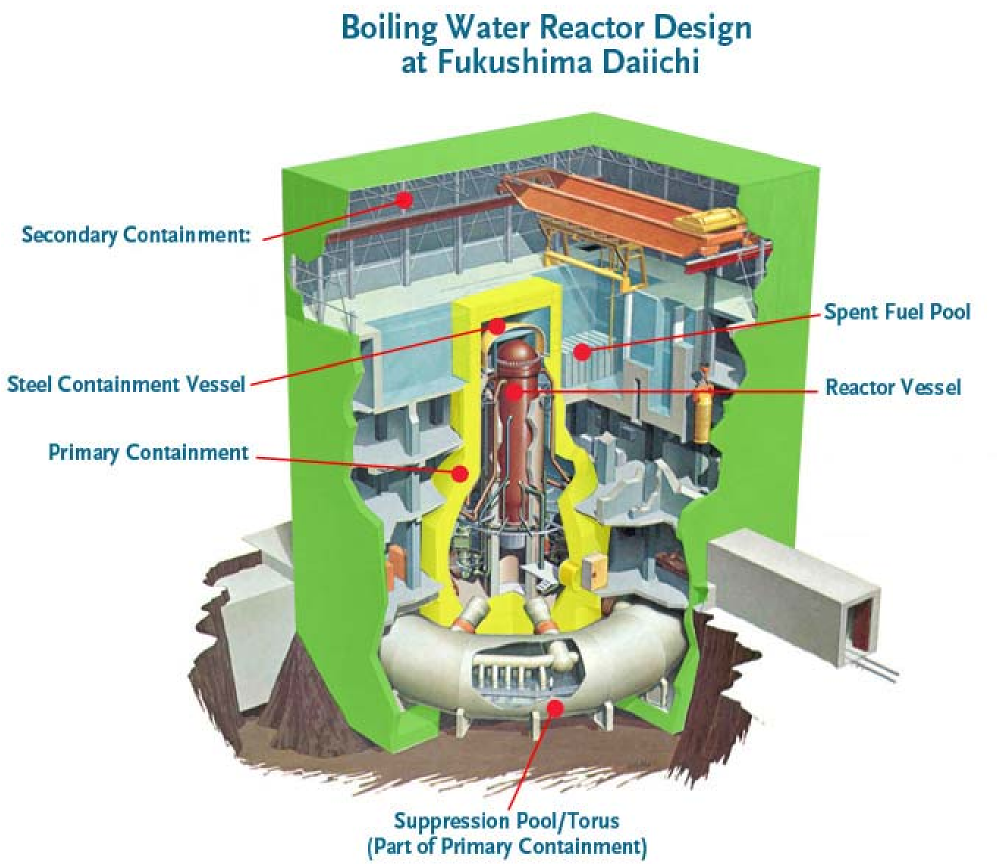
SNF Pool with High-Density Racks



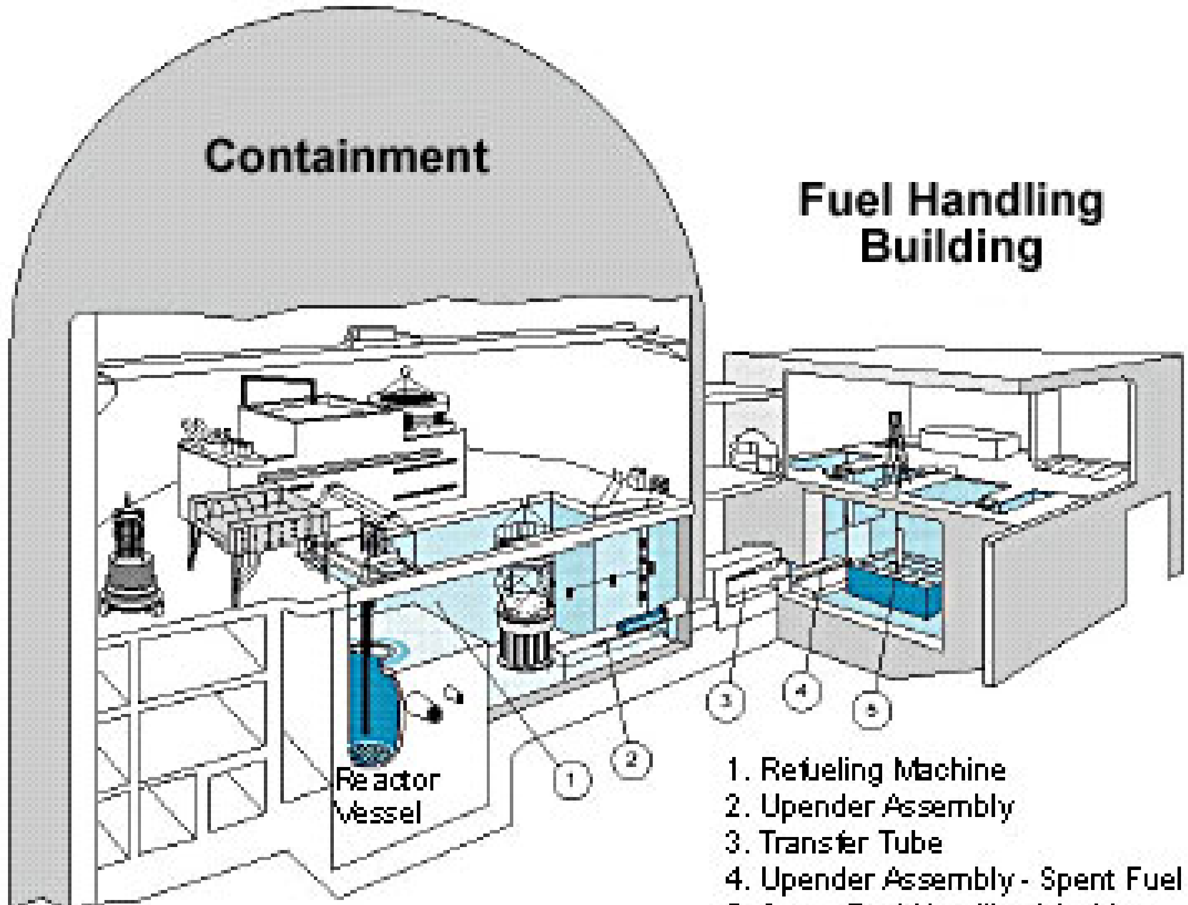
Low-Density Rack for PWR Spent Fuel



Typical BWR Layout: Mark I Containment

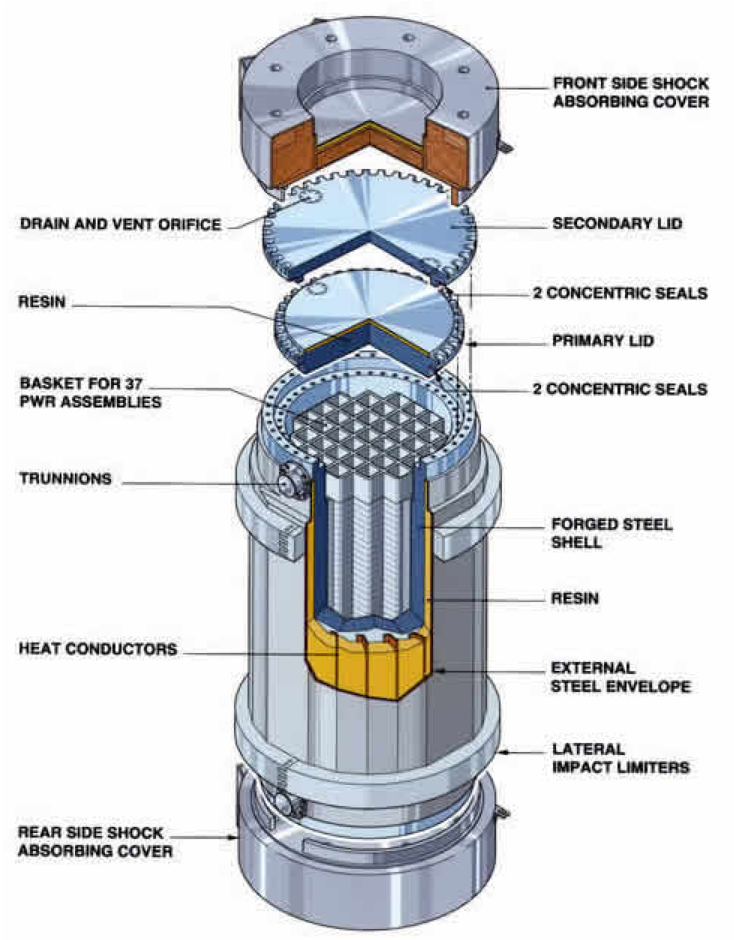


Typical PWR Layout

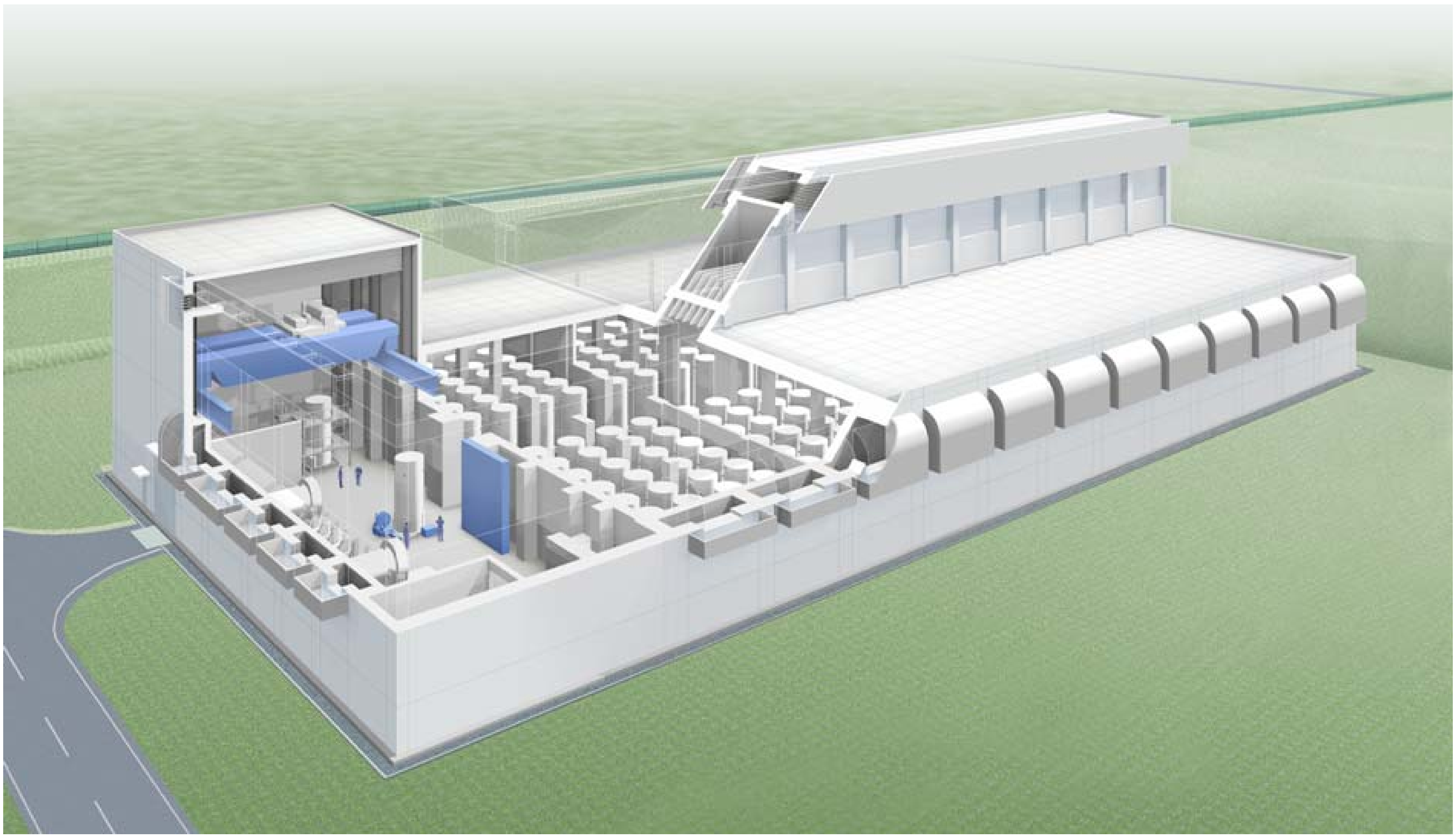


Dry Cask: Modular Type (Holtec)

Dry Cask: Monolithic Type

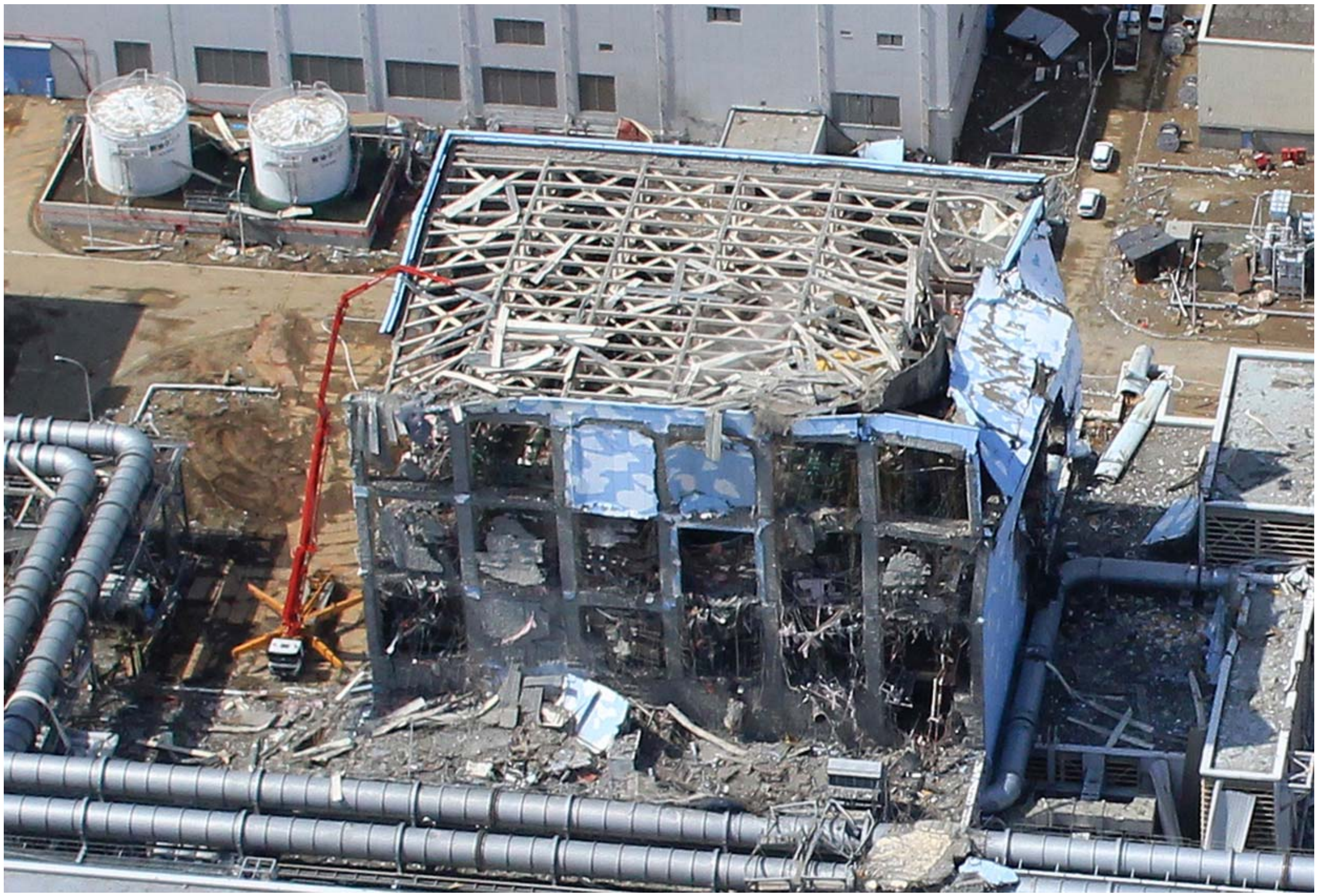


Mutsu Facility for Dry Storage of SNF



Rokkasho Site

Fukushima #1 Unit 4



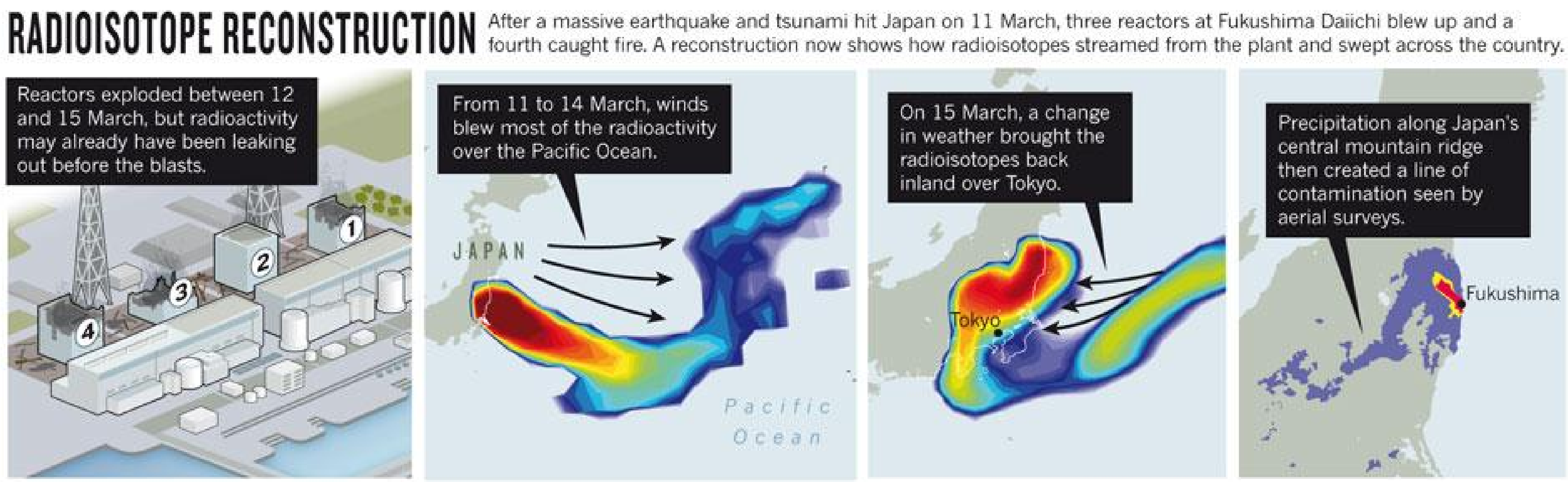
Amounts of Radioactive Cesium-137, Chernobyl and Fukushima

Chernobyl release to atmosphere, 1986	85 PBq
Fukushima #1 release to atmosphere, 2011	36 PBq (6.4 PBq deposited on Japan)
In Fukushima #1 Units 1-3 reactor cores	940 PBq (total for 3 cores)
In Fukushima #1 Units 1-4 spent-fuel pools	2,200 PBq (total for 4 pools)

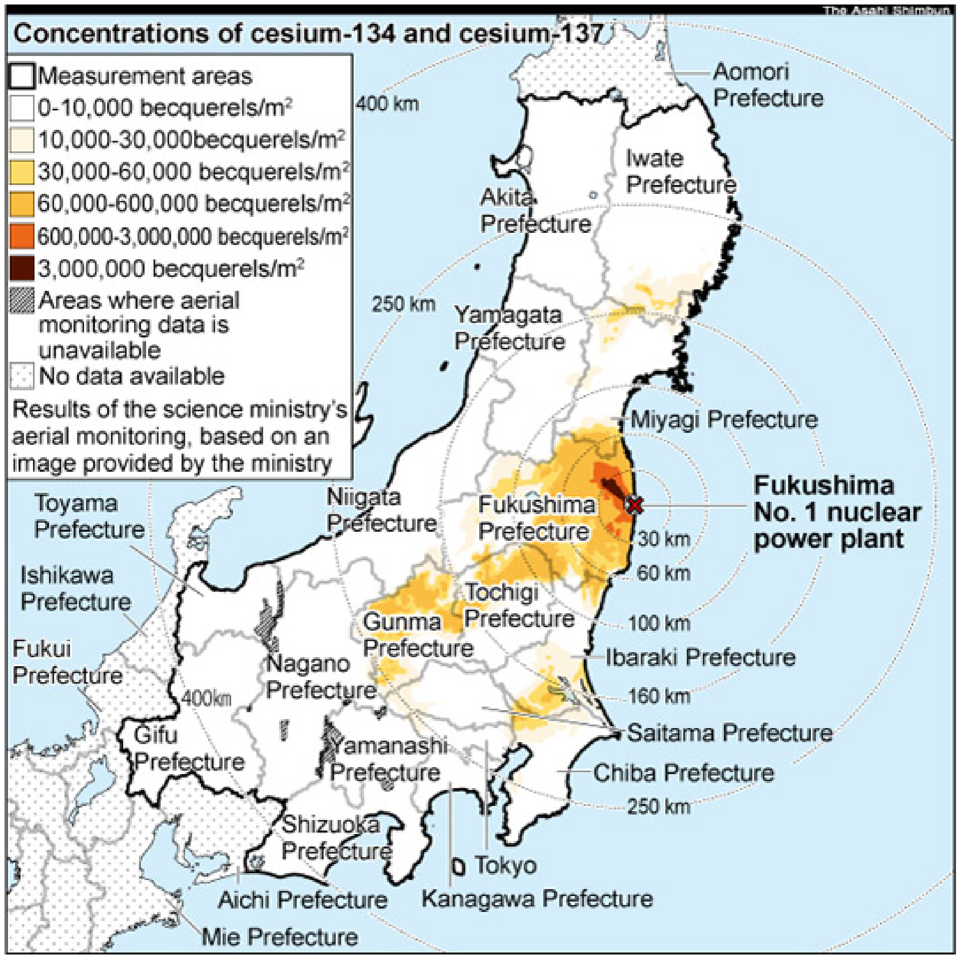
Source: Stohl et al, 2011

Atmospheric Plume from Fukushima Release

Source: Nature, Vol 478, 25 October 2011, pp 435-436

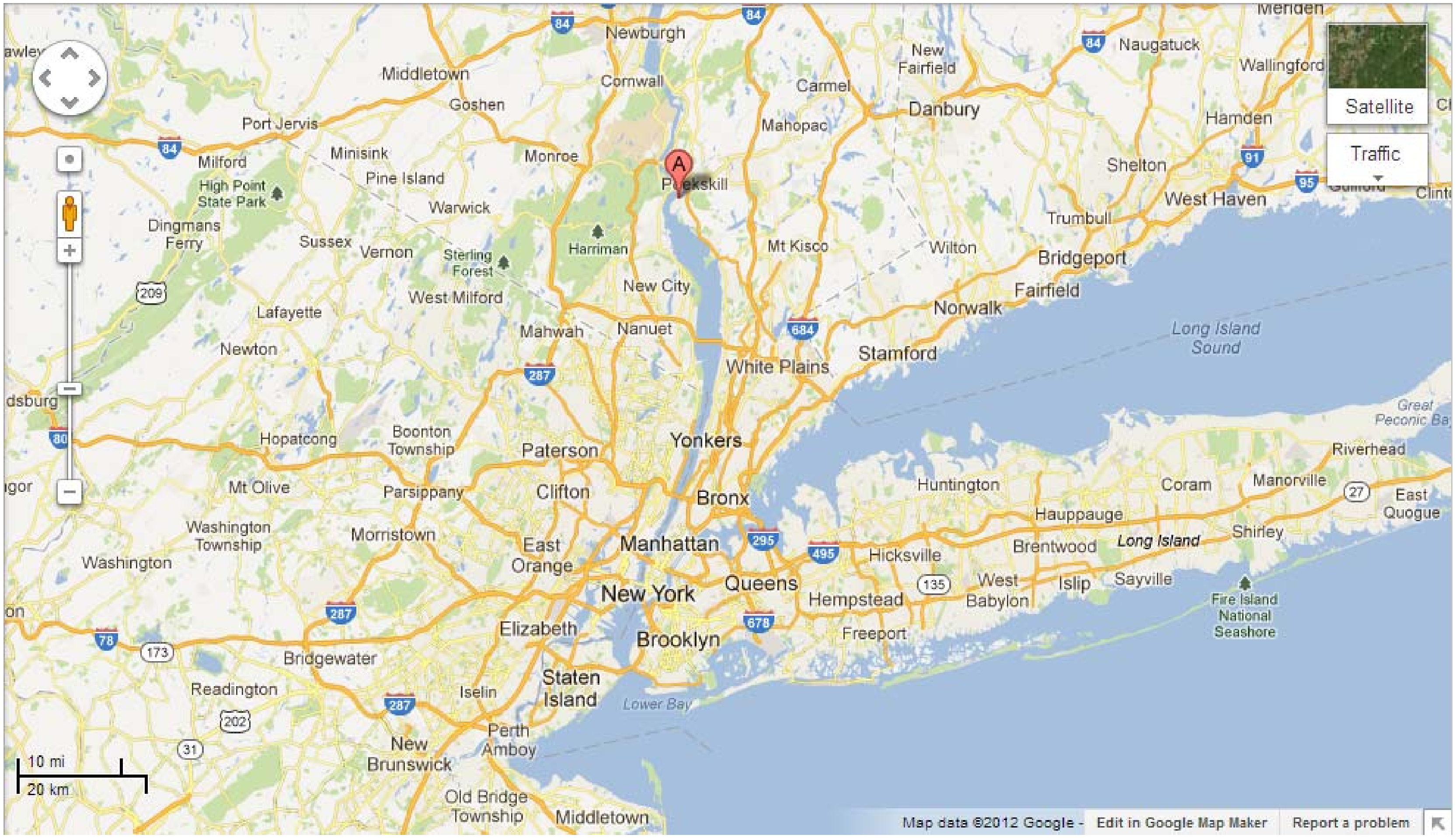


Deposition of Radioactive Cesium Released During Fukushima Accident



Source: Asahi Shimbun, November 2011

Location of the Indian Point Site



Indian Point Nuclear Power Plants

(Right to left: Unit 2, Unit 1, Unit 3)

Dry-Cask Storage Facility at Indian Point

A Citizen Opinion on Indian Point

Data on Indian Point Nuclear Power Plants

(Data from USNRC and licensees)

Indicator	Unit 1	Unit 2	Unit 3
License period	03/26/1962 to 10/31/1974	09/28/1973 to 09/28/2013	12/12/1975 to 12/12/2015
Rated power	615 MWt	3,216 MWt	3,216 MWt
Fuel in core	N/A	193 assemblies	193 assemblies
Pool capacity	N/A	1,376 assemblies	1,345 assemblies
SNF yield over license period	404 assemblies	est. 1,721 assemblies	est. 1,683 assemblies

Data on Dry-Cask Storage Facility at Indian Point

(Data from licensee)

Indicator	Value
Cask capacity	32 assemblies
Facility capacity	• 78 casks on present pad • 40 casks on future pad
IP1 fuel, now stored	160 assemblies in 5 casks (244 assemblies went to West Valley for reprocessing)
IP2 fuel, potential storage	1,721 assemblies in 54 casks
IP3 fuel, potential storage	1,683 assemblies in 53 casks

Licensee Estimates of Accident Probabilities & Outcomes at Indian Point Nuclear Power Plants

Indicator	Unit 2	Unit 3
Core damage frequency (int. + ext. + uncertainty)	1.4E-04 per RY	9.2E-05 per RY
Conditional prob. of Early High release, given core damage	3.6 percent	8.2 percent
Cs-137 in Early High release	96 PBq	63 PBq
Av. offsite costs of Early High release	US$66 billion	US$56 billion

IRSN-Estimated Costs (billion Euro) from Atmos. Release of 100 PBq of Cs-137 at Dampierre

Cost Category	Base-Case Costs	Low-Case Costs	High-Case Costs
Onsite costs	10	5	15
Offsite rad. costs	106	38	281
Contaminated territories	393	130	4,875
Image costs	130	75	176
Costs re. power prodn.	90	30	360
Indirect effects	31	9	50
Total	760	290	5,760

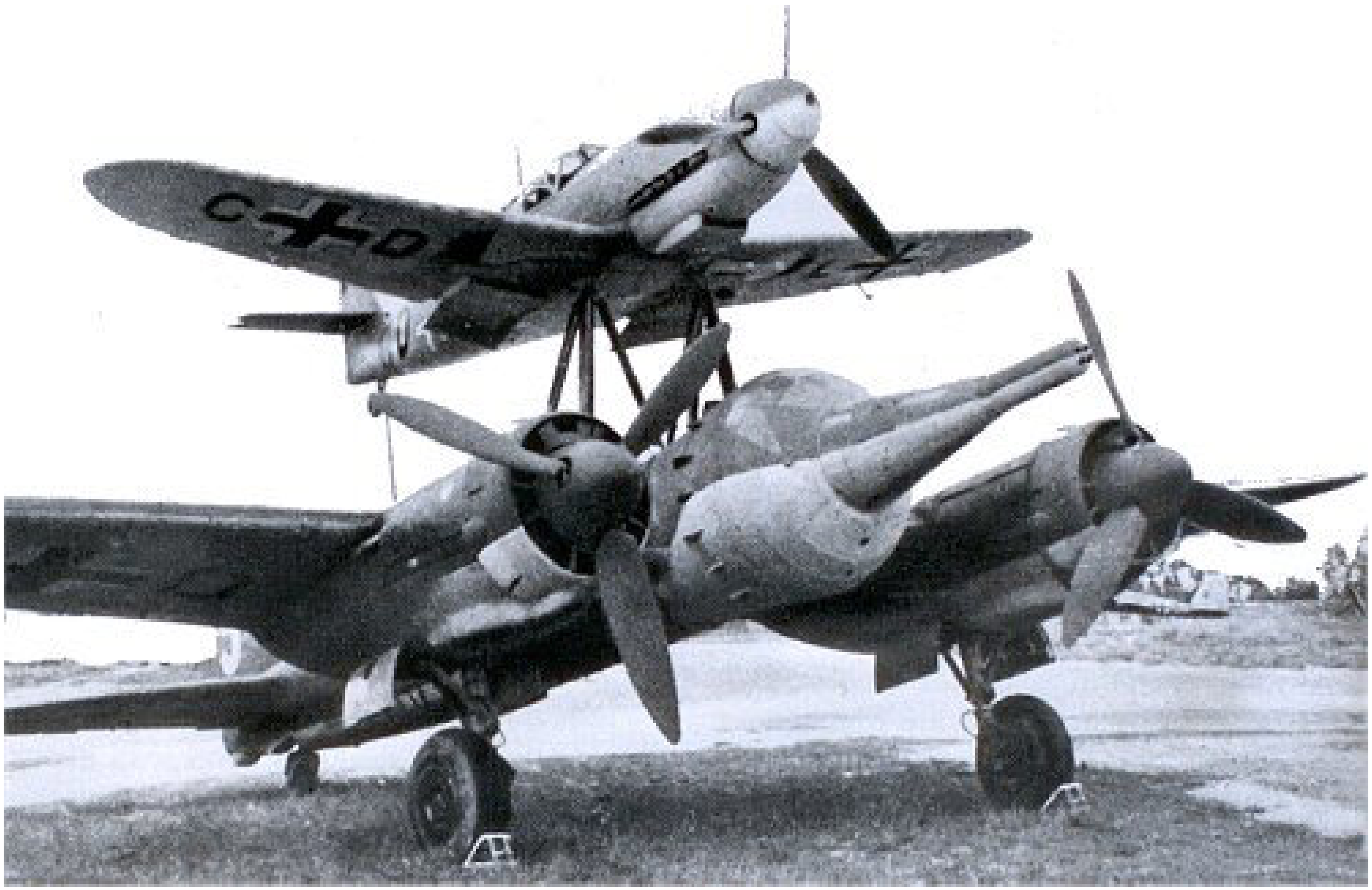
Potential Types of Attack on a Reactor or Spent-Fuel Installation

- Type 1: Vaporization or Pulverization
  - Total or partial vaporization or pulverization
- Type 2: Rupture and Dispersal (Large)
  - Structures are broken open
  - Fuel is dislodged and broken apart
- Type 3: Rupture and Dispersal (Small)
  - Structures are penetrated but retain basic shape
  - Fuel rods retain basic shape
- Type 4: Precise, Informed Targeting
  - Structures are penetrated
  - Zircaloy combustion is initiated

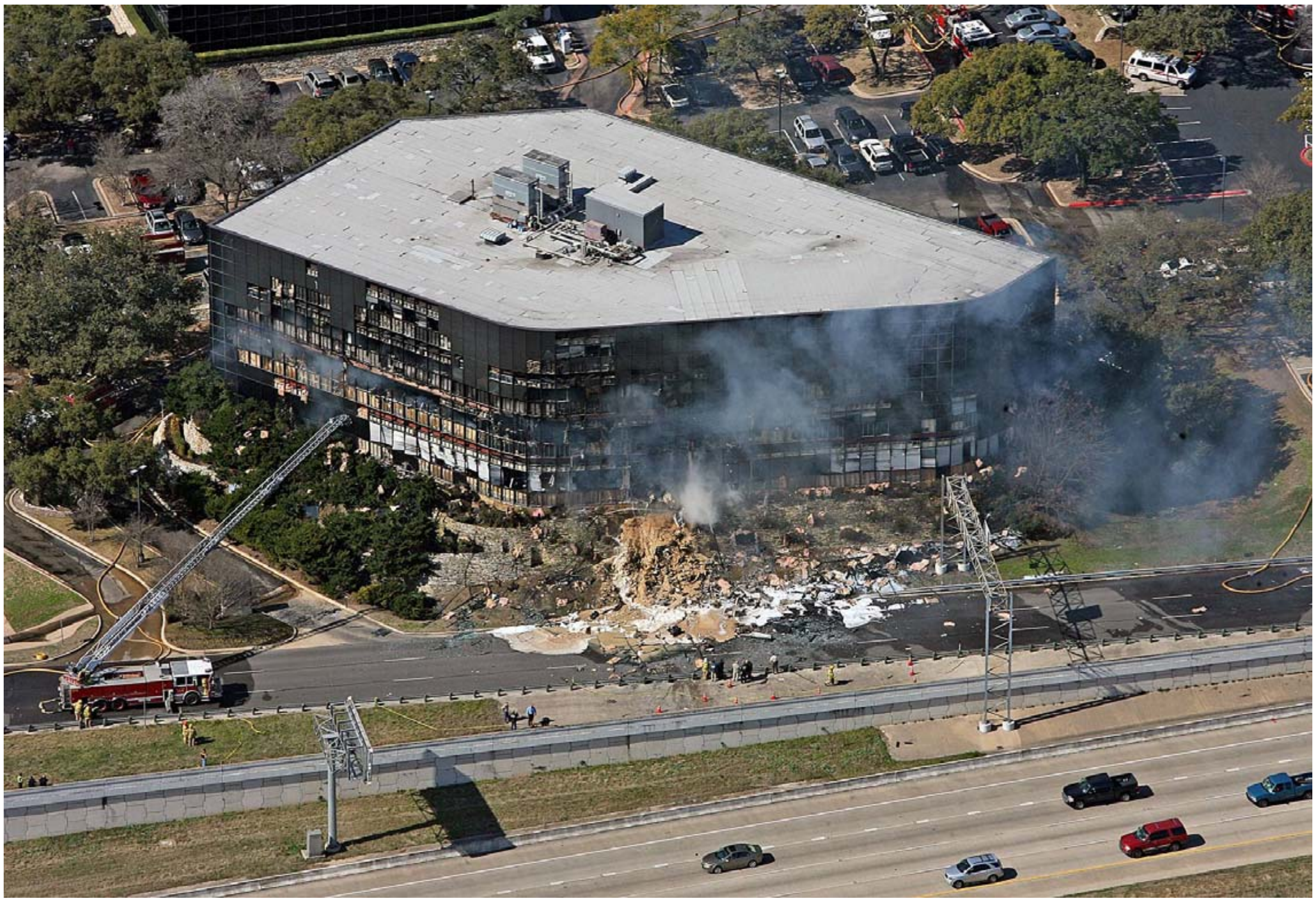
A Potential Instrument of Attack: The Shaped Charge

Above: The RPG 1943 was the Soviet equivalent of the German Wurfmine, but it used a fabric strip stabilizer tail to keep the hollow charge warhead pointing towards the target tank when in night. The tail was ejected from the throwing handle after the grenade had been thrown and after the arming pin had been removed.

The Mistel Shaped-Charge Delivery System



Result of Aircraft Suicide Attack on IRS Building, Austin, Texas, February 2010

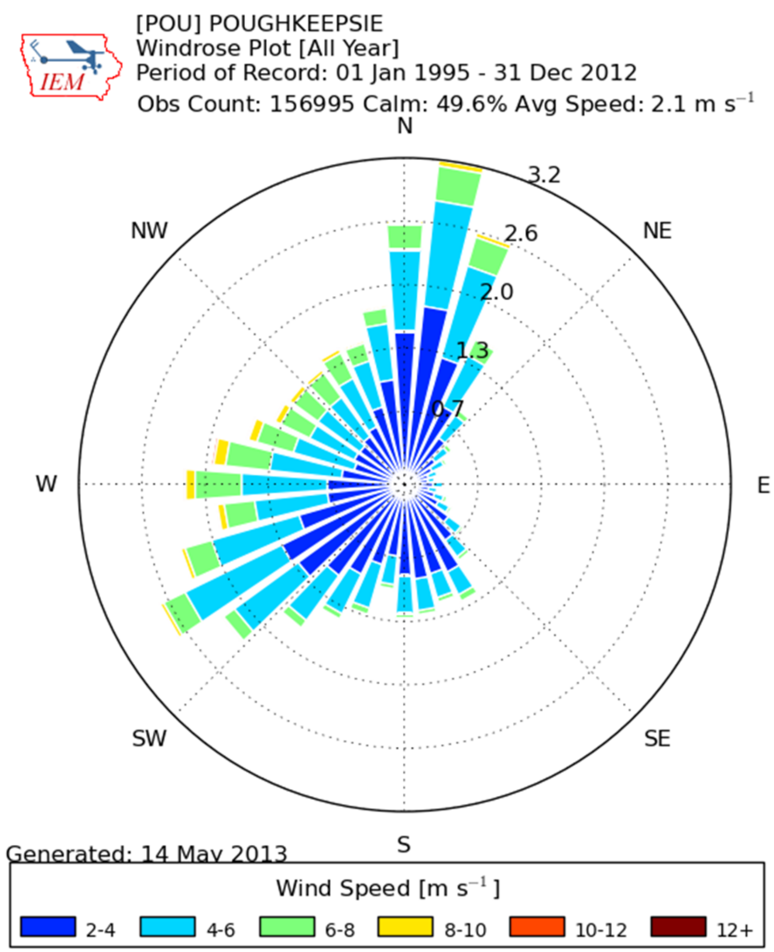


Raytheon Shaped-Charge Test: Before

Raytheon Shaped-Charge Test: After

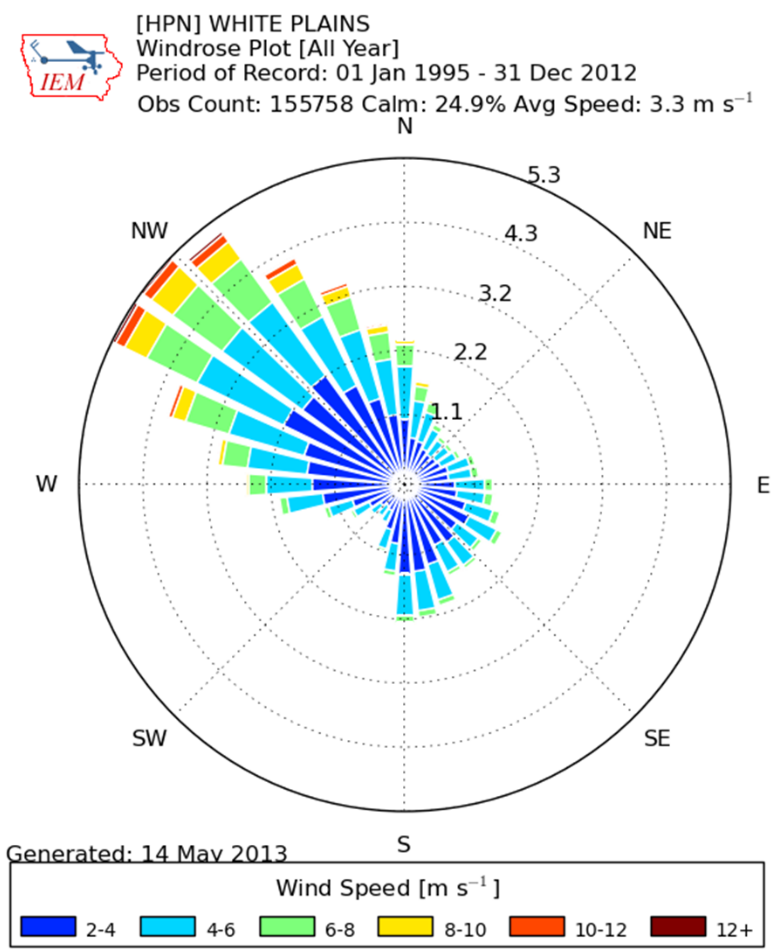
Wind Rose, Poughkeepsie Airport, NY

(ASOS data, 10 m height, wind blowing <u>from</u>, plot by Iowa State Univ.)

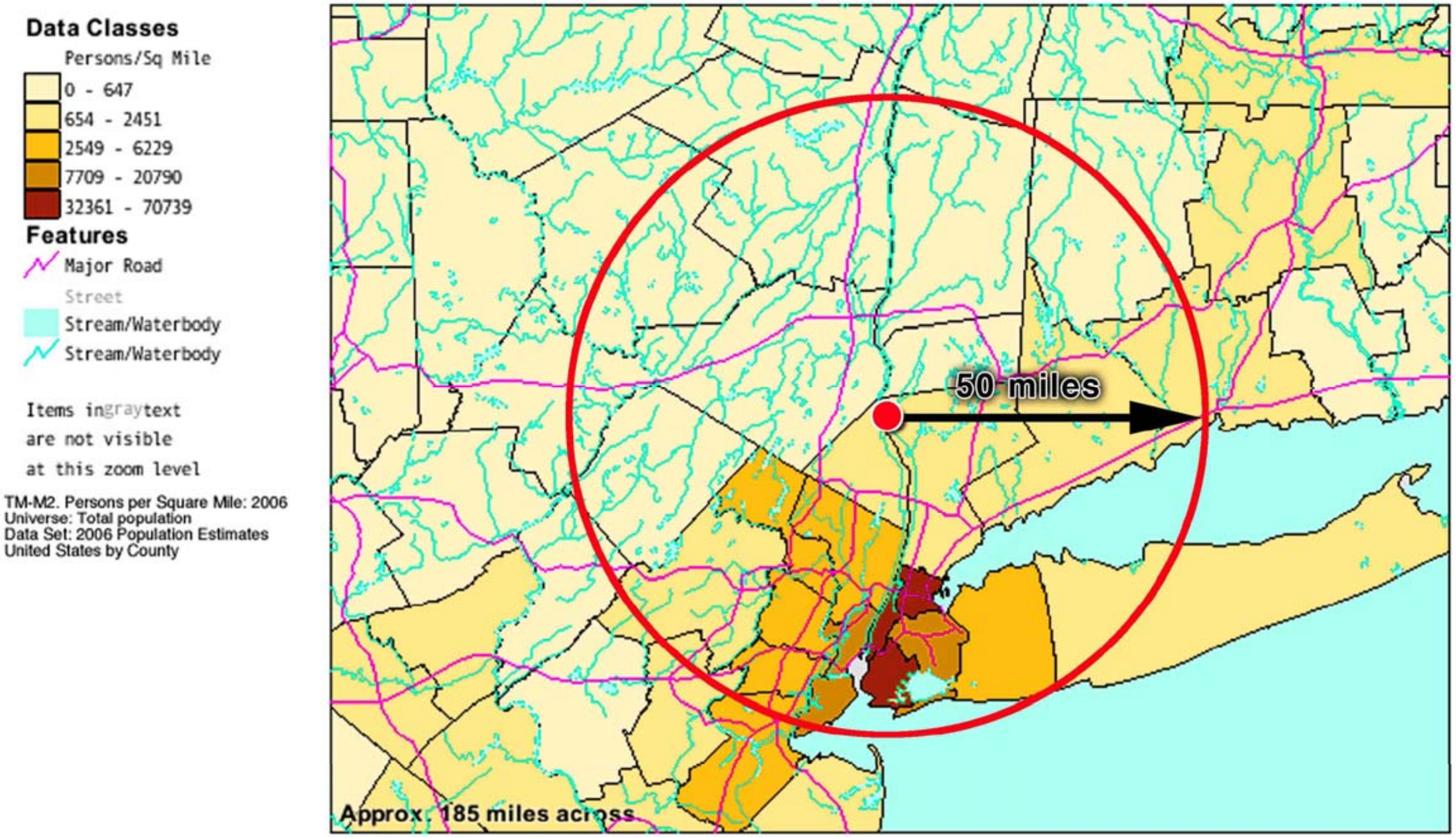


Wind Rose, White Plains Airport, NY

(ASOS data, 10 m height, wind blowing <u>from</u>, plot by Iowa State Univ.)



Population Density In The Area Around Indian Point



Source:
NY Attorney General's Office

Note:
1.0 person/sq. mile = 0.39 person/sq. km

Population Data Re. Indian Point

(IP data from USNRC, other data from US Census Bureau)

Region	Population	Population Density (person/sq. km)
Within 32 km of Indian Point	1,113,000	350
Within 80 km of Indian Point	16,792,000	840
New York State	19,570,000	160
New York City	8,245,000	10,600

Atmos. Release Examples for IP Case Study

- **Example #1:** Linked releases from IP2 reactor (discharge burnup = 55 GWt-d/Mg HM) and high-density IP2 pool (inventory = 1,150 assemblies with av. age of 15 yr and av. burnup of 50 GWt-d/Mg HM)
- **Example #2:** Release from IP2 reactor (discharge burnup = 55 GWt-d/Mg HM) with no release from low-density IP2 pool (inventory = 200 assemblies with av. age of 2.5 yr and av. burnup of 55 GWt-d/Mg HM)
- **Example #3:** Release from 1 dry cask (32 assemblies with av. age of 15 yr and av. burnup of 50 GWt-d/Mg HM)
- **NYC Exposure Scenario:** For each example, calculate collective dose across a wedge sector between 40 km and 70 km from IP, with a population density of 10,600 person/sq. km

NYC Exposure Scenario: Findings of IP Case Study

Scenario Description: For each release example, calculate collective dose across a wedge sector between 40 km and 70 km from IP, with a population density of 10,600 person/sq. km. Thus, exposed population = 4.37 million.

Monetary Equivalent: US$510,000 per person-Sv

Release Example	Collective Dose (million person-Sv)	Monetary Equivalent of Collective Dose (billion US$)
Example #1	33.9	17,300
Example #2	5.0	2,550
Example #3	0.80	410

Collateral Implications: Indian Point Case

- Societal and strategic implications of radiological risk
- Opportunities to reduce radiological risk
- Imperatives and opportunities for investment in sustainable infrastructure, and role of nuclear power