Long-term Relocation Areas
Resulting From a Spent Fuel Fire at Indian Point

- Multi-year relocation would occur for red and orange areas
- At Chernobyl and Fukushima, a large fraction of the population also evacuated out of the yellow area.

- Maps based on relocation standards used for Chernobyl and Fukushima and recommended by the EPA
- Maps based on historical weather for the first date of each month of 2015
Maps by Michael Schoeppner, PhD, International Data Centre, Comprehensive Nuclear-Test-Ban Treaty Organization, Vienna.
Relocation areas and populations

- Average relocation would be about 60,000 square kilometers
  - (30 times the area of New York City)

- Average relocated population would be 13 million
  - (1.5 times the population of New York City)

<table>
<thead>
<tr>
<th>Month (release beginning on first day of month, 2015)</th>
<th>Area Interdicted (km² contaminated above 1.5 MBq/m²)</th>
<th>Population in area</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>7,500</td>
<td>830,000</td>
</tr>
<tr>
<td>February</td>
<td>61,000</td>
<td>8,200,000</td>
</tr>
<tr>
<td>March</td>
<td>60,000</td>
<td>9,600,000</td>
</tr>
<tr>
<td>April</td>
<td>25,000</td>
<td>9,400,000</td>
</tr>
<tr>
<td>May</td>
<td>23,000</td>
<td>15,400,000</td>
</tr>
<tr>
<td>June</td>
<td>109,000</td>
<td>29,000,000</td>
</tr>
<tr>
<td>July</td>
<td>73,000</td>
<td>13,800,000</td>
</tr>
<tr>
<td>August</td>
<td>12,000</td>
<td>5,700,000</td>
</tr>
<tr>
<td>September</td>
<td>23,000</td>
<td>16,500,000</td>
</tr>
<tr>
<td>October</td>
<td>175,000</td>
<td>34,900,000</td>
</tr>
<tr>
<td>November</td>
<td>38,000</td>
<td>5,000,000</td>
</tr>
<tr>
<td>December</td>
<td>129,000</td>
<td>8,400,000</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>61,292</strong></td>
<td><strong>13,060,833</strong></td>
</tr>
</tbody>
</table>
Spent fuel fire on U.S. soil could dwarf impact of Fukushima

By Richard Stone May. 24, 2016, 8:00 PM

A fire from spent fuel stored at a U.S. nuclear power plant could have catastrophic consequences, according to new simulations of such an event.

A major fire “could dwarf the horrific consequences of the Fukushima accident,” says Edwin Lyman, a physicist at the Union of Concerned Scientists, a nonprofit in Washington, D.C. “We’re talking about trillion-dollar consequences,” says Frank von Hippel, a nuclear security expert at Princeton University, who teamed with Princeton’s Michael Schoeppner on the modeling exercise.

The revelations come on the heels of a report last week from the U.S. National Academies of Sciences, Engineering, and Medicine on the aftermath of the 11 March 2011 earthquake and tsunami in northern Japan. The report details how a spent fuel fire at the Fukushima Daiichi Nuclear Power Plant that was crippled by the twin disasters could have released far more radioactivity into the environment.

The nuclear fuel in three of the plant’s six reactors melted down and released radioactive plumes that contaminated land downwind. Japan declared 1100 square kilometers uninhabitable and relocated 88,000 people. (Almost as many left voluntarily.) After the meltdowns, officials feared that spent fuel stored in pools in the reactor halls would catch fire and send radioactive smoke across a much wider swath of eastern Japan, including Tokyo. By a stroke of luck, that did not happen.

But the national academies’s report warns that spent fuel accumulating at U.S. nuclear plants is also vulnerable. After fuel is removed from a reactor core, the radioactive fission products continue to decay, generating heat. All nuclear power plants store the fuel onsite at the bottom of deep pools for at least 4 years while it slowly cools. To keep it safe, the academies report recommends that the U.S. Nuclear Regulatory Commission (NRC) and nuclear plant operators beef up systems for monitoring the pools and topping up water levels in case a facility is damaged. The panel also says plants should be ready to tighten security after a disaster.

At most U.S. nuclear plants, spent fuel is densely packed in pools, heightening the fire risk. NRC has estimated that a major fire at the spent fuel pool at the Peach Bottom nuclear power plant in Pennsylvania would displace an estimated 3.46 million people from 31,000 square kilometers of contaminated land, an area larger than New Jersey. But Von Hippel and Schoeppner think that NRC has grossly underestimated the scale and societal costs of such a fire.

NRC used a program called MACCS2 for modeling the dispersal and deposition of the radioactivity from a Peach Bottom fire. Schoeppner and Von Hippel instead used HYSPLIT, a program able to craft more sophisticated scenarios based on historical weather data for the whole region.
Nightmare scenarios

A simulated spent fuel fire at the Peach Bottom nuclear power plant in Pennsylvania had a devastating impact on the mid-Atlantic region. Click on the dates to see the extent of contamination, which depended on weather patterns.Courtesy of F. Von Hippel and M. Schoeppner

1 Jan. 2015

1 April 2015
In their simulations, the Princeton duo focused on Cs-137, a radioisotope with a 30-year half-life that has made large tracts around Chernobyl and Fukushima uninhabitable. They assumed a release of 1600 petabecquerels, which is the average amount of Cs-137 that NRC estimates would
be released from a fire at a densely packed pool. It’s also approximately 100 times the amount of Cs-137 spewed at Fukushima. They simulated such a release on the first day of each month in 2015.

The contamination from such a fire on U.S. soil “would be an unprecedented peacetime catastrophe,” the Princeton researchers conclude in a paper to be submitted to the journal Science & Global Security. In a fire on 1 January 2015, with the winds blowing due east, the radioactive plume would sweep over Philadelphia, Pennsylvania, and nearby cities. Shifting winds on 1 July 2015 would disperse Cs-137 in all directions, blanketing much of the heavily populated mid-Atlantic region. Averaged over 12 monthly calculations, the area exposed to more than 1 megabecquerel per square meter -- a level that would trigger a relocation order -- is 101,000 square kilometers. That’s more than three times NRC’s estimate, and the relocation of 18.1 million people is about five times NRC’s estimates.

NRC has long mulled whether to compel the nuclear industry to move most of the cooled spent fuel now held in densely packed pools to concrete containers called dry casks. Such a move would reduce the consequences and likelihood of a spent fuel pool fire. As recently as 2013, NRC concluded that the projected benefits do not justify the roughly $4 billion cost of a wholesale transfer. But the national academies’s study concludes that the benefits of expedited transfer to dry casks are fivefold greater than NRC has calculated.

“NRC’s policies have underplayed the risk of a spent fuel fire,” Lyman says. The academies panel recommends that NRC “assess the risks and potential benefits of expedited transfer.” NRC spokesperson Scott Burnell in Washington, D.C., says that the commission’s technical staff “will take an in-depth look” at the issue and report to NRC commissioners later this year.
Comparison of Cesium 137 Inventories

Sources: CDC 2000, NCRP No. 154, DOE GC-859, Exchange Monitor 01-2017, DOE EIS-0250, Appendix A, (PWR/ Burnup = 41,200 MWd/MTHM, enrichment = 3.75 percent, decay time = 23 years.)
Average number of annual incidents over 2005-2013 per 10,000 miles of onshore gas transmission pipe by decade of pipe installation

As of March 2015.
Sources: U.S. Pipeline and Hazardous Materials Safety Administration, Pipeline Safety Trust
Calculation from David Lochbaum

Pipeline calculation check by Dave Lochbaum, Union of Concerned Scientists

From NRC Regulatory Guide 1.91, Rev. 2, April 2013

Equation (1):

\[ R_{\text{min}} = Z \times W^{0.331} \]

where
- \( R_{\text{min}} \) = distance from explosion to point where overpressure will drop to 1.0 psi
- \( Z \) = scaled distance = 45 ft/ft^{0.331} when \( R \) is in feet and \( W \) is in pounds
- \( Z \) = scaled distance = 38 m/m^{0.331} when \( R \) is in meters and \( W \) in kilograms

Check NUREG-1805 (December 2004) Figure 15-3 supports 45 ft/ft^{0.331} for 3 psi overpressure

Equation (2):

\[ W_{\text{eff}} = (\text{Heq}/\text{He}) \times W_{\text{exp}} \]

where
- \( W_{\text{eff}} \) = effective charge equivalent
- \( W_{\text{exp}} \) = weight of the explosive charge
- \( \text{Heq} \) = heat of detonation of the explosive
- \( \text{He} \) = heat of detonation of TNT

Equation (3):

\[ E = \alpha \times \triangle \text{He} \times m_f \]

where
- \( E \) = blast wave energy, BTU or kilojoules
- \( \alpha \) = yield (fraction of available combustion energy participating in blast wave) = 5% from Table 1
- \( \triangle \text{He} \) = theoretical net heat of combustion (BTU/lb or kilojoules/kilogram)
- \( m_f \) = mass of flammable vapor released (pounds mass or kilograms)

Equation (4):

\[ W_{\text{flam}} = E / (1500 \text{ BTU/pound mass}) \text{ or } E / (6420 \text{ kilojoules/kilogram}) \]

From FOIA-2015-0076:

\[ \triangle \text{He} = 50,030 \text{ kilojoules/kilogram} \]

Check NUREG-1805 (December 2004) Table 3-2 gives 50,000 KJ/kg for LNG and 46,000 KJ/kg for LPG

Check NUREG-1805 (December 2004) Table 15-2 gives 50,010 KJ/kg for Methane gas

Check NUREG-1805 (December 2004) Table 15-2 gives 46,360 KJ/kg for Propane gas

Check NUREG-1805 (December 2004) Table 15-2 gives 47,491 KJ/kg for Ethane gas

\[ m_f = 376,000 \text{ kilograms} \times 250,000 \text{ kilograms} \times 100,000 \text{ kilograms} = 6,760,000 \text{ kilograms} \]

Solving Equation (3):

\[ E = \alpha \times \triangle \text{He} \times m_f \]

\[ E = 0.05 \times 50,030 \text{ kilojoules/kilogram} \times 6,760,000 \text{ kilograms} \]

\[ E = 1,093,004,000 \text{ kilojoules for 6,760,000 kilograms} \]

\[ E = 940,564,000 \text{ kilojoules for 3,760,000 kilograms} \]

Solving Equation (4):

\[ W_{\text{flam}} = E / (1500 \text{ BTU/pound mass}) \text{ or } E / (6420 \text{ kilojoules/kilogram}) \]

\[ W_{\text{flam}} = 320,182 \text{ kilometers for 6,760,000 kilograms} \]

\[ W_{\text{flam}} = 522,791 \text{ kilometers for 3,760,000 kilograms} \]

Solving Equation (1):

\[ R_{\text{min}} = Z \times W^{0.331} \]

\[ R_{\text{min}} = 1,301 \text{ meters for 6,760,000 kilograms} \]

\[ R_{\text{min}} = 4,233 \text{ feet for 6,760,000 kilograms} \]

\[ R_{\text{min}} = 0.81 \text{ miles for 6,760,000 kilograms} \]

\[ R_{\text{min}} = 1,670 \text{ meters for 3,760,000 kilograms} \]

\[ R_{\text{min}} = 5,485 \text{ feet for 3,760,000 kilograms} \]

\[ R_{\text{min}} = 0.67 \text{ miles for 3,760,000 kilograms} \]

Blast Radius of 4200 feet for 3 minute release
Calculation Summary from NRC Professional Engineer

\[ R_{\text{min}} = Z \times W^{1/3} \]  \hspace{1cm} (1)

where

- \( R_{\text{min}} \) = distance from explosion where \( P_{50} \) will equal 1.0 psi (meters)
- \( W \) = mass of TNT (kilograms)
- \( Z \) = scaled distance equal to 18 m/kg\(^{1/3}\)

For a mass of 380 metric tons of TNT, \( R_{\text{min}} \) is calculated as follows from Equation 1:

\[ R_{\text{min}} = 18 \times (380,000)^{1/3} \approx 1,300 \text{ meters} = 1.3 \text{ km} \]

Thus, assuming a rupture of the section Algonquin Incremental Market pipeline passing through Indian Point were to take three minutes to isolate and were to release 676,000 kg of natural gas and assuming that the released mass of gas was to result in a vapor cloud explosion (VCE) with an explosive yield efficiency factor of 5%, then it is possible that structures within 1.3 kilometers (4300 feet) of the rupture would experience adverse affects from that explosion.

Blast radius of 4300 feet
Calculation From DOE
Professional Engineer

Paul

Per your request, I have reviewed your calculation assuming the average flow rate from a ruptured line is 1877 Kg per second and lasting for 360 seconds. This information was provided from a response to FOIA 2015-0246.
DHC is a constant of 50030

Applying equation from FOIA

\[ VTNT = M_f \times DHC \times Y \times \sqrt[1/3]{4500} = 675,720_{Kg(TNT)} \]

This is equivalent to 1,486,584 pounds or 743 tons of TNT after 6 Minutes.

The NRC provides the equation \( d = 45 \times \sqrt{(w)} \) where \( d \) is the minimum safe distance in feet.

Applying this NRC equation \(^1\) equals 4,185 feet as the Minimum blast radius from a 6 minute release using the following:

\[ R_{(3 \text{ Minutes})} = 45 \times (w_{\text{Promp}})^{1/3} = 45 \times \sqrt[1/3]{\frac{M_f \times DHC \times Y \times \sqrt{(w_{\text{Promp}})}}{4500}} = 45 \times \sqrt{\frac{(Total \ flow \ after \ 3 \ Minutes)_{kg} \times 50030 \times 0.05}{4500}} \]

Conclusion

Assuming a Yield of 5%, the lowest value from NRC Regulatory Guide 1.91, and a DHC of 50030 from FOIA 2015-0076, my calculated blast radius is 4,185 feet, consistent with Dave Lochbaum’s calculated radius of 4269 feet and in total conflict with Entergy’s and the NRC’s results of about 1100 feet from Entergy’s 10 CFR 50.59 analysis.

\(^1\) Co-locating Nuclear Plants with Natural Gas Pipelines
Paul Blanch  Energy Consultant
Calculation by
Paul Blanch, PE

Indian Point Damaging Blast Radius (1 PSI)
vs time from NRC RG 1.19 Equations

Spent Fuel Dry Casks 3400 feet
RWST Unit 2 3100 feet
Spent Fuel Pool 2700 feet
Unit 3 Control room 2700 feet
RWST Unit 3 2700 feet
Condensate Storage tank 2400 feet
Unit 2 Control room 2100 feet
Switchgear room 2100
Existing pipelines 1800 feet
City Water Storage tank 1600 feet
Fuel Oil Storage Tanks 1500 feet
Switchyard 120 feet
DG backup fuel 110 feet

Blast radius 3000-4000 feet

Co-locating Nuclear Plants with
Natural Gas Pipelines
Paul Blanch Energy Consultant