


United States Nuclear Regulatory Commission Official Hearing Exhibit	
In the Matter of:	Entergy Nuclear Operations, Inc. (Indian Point Nuclear Generating Units 2 and 3)
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What are the odds? US nuke plants ranked by quake risk

So much for San Andreas: Reactors in East, Midwest, South have highest chance of damage



Mike Segar / Reuters

Where's the U.S. nuclear power plant with the greatest risk of being damaged by an earthquake? Not on the Pacific coastline. It's on the Hudson River.



By **Bill Dedman** Investigative reporter
msnbc.com
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What are the odds that a nuclear emergency like the one at Fukushima Dai-ichi could happen in the central or eastern United States? They'd have to be astronomical, right? As a pro-nuclear commenter on msnbc.com put it this weekend, "There's a power plant just like these in Omaha. If it gets hit by a tsunami...."

It turns out that the U.S. Nuclear Regulatory Commission has calculated the odds of an earthquake causing catastrophic failure to a nuclear plant here. Each year, at the typical nuclear reactor in the U.S., there's a 1 in 74,176 chance of an earthquake strong enough to cause damage to the reactor's core, which could expose the public to radiation. No tsunami required. That's 10 times more likely than you winning \$10,000 by buying a single ticket in the Powerball multistate lottery, where the chance is 1 in 723,145.

And it turns out that the nuclear reactor in the United States with the highest risk of an earthquake causing core damage is not the Diablo Canyon Power Plant, with its twin reactors tucked between the California coastline and the San Andreas Fault.

It's not the San Onofre Nuclear Generating Station, a four-hour drive down the Pacific coast at San Clemente, surrounded by fault lines on land and under the ocean.

It's not on the Pacific Coast at all. It's on the Hudson River.

One in 10,000

The reactor with the highest risk rating is 24 miles north of New York City, in the village of Buchanan, N.Y., at the Indian Point Energy Center. There, on the east bank of the Hudson, Indian Point nuclear reactor No. 3 has the highest risk of earthquake damage in the country, according to new NRC risk estimates provided to msnbc.com.

A ranking of the nation's 104 commercial nuclear reactors is shown at the bottom of this article, listing the NRC estimate of risk of an earthquake causing core damage.

The chance of an earthquake causing core damage at Indian Point 3 is estimated at 1 in 10,000 each year. Under NRC guidelines, that's right on the verge of requiring "immediate concern regarding adequate protection" of the public. The two reactors at Indian Point generate up to one-third of the electricity for New York City. The second reactor, Indian Point 2, doesn't rate as risky, with 1 chance in 30,303 each year.

Update: [Gov. Cuomo orders review of N.Y. reactor after report on quake data.](#)

The plant with the second highest risk? It's in Massachusetts. Third? Pennsylvania. Then Tennessee, Pennsylvania again, Florida, Virginia and South Carolina. Only then does California's Diablo Canyon appear on the list, followed by Pennsylvania's Three Mile Island.

The odds take into consideration two main factors: the chance of a serious quake, and the strength of design of the plant.

Nuclear power plants built in the areas usually thought of as earthquake zones, such as the California coastline, have a surprisingly low risk of damage from those earthquakes. Why? They built anticipating a major quake.

Other plants in the East, South and Midwest, where the design standards may have been lower because the earthquake risk was thought to be minimal, now find themselves at the top of the NRC's danger list.

The chance of an earthquake that would cause core damage ranges from Indian Point's 1 chance in 10,000 each year, a relatively higher risk, to the Callaway nuclear plant in Fulton, Mo., where the NRC set the lowest risk, 1 chance in 500,000 each year.

Playing the odds

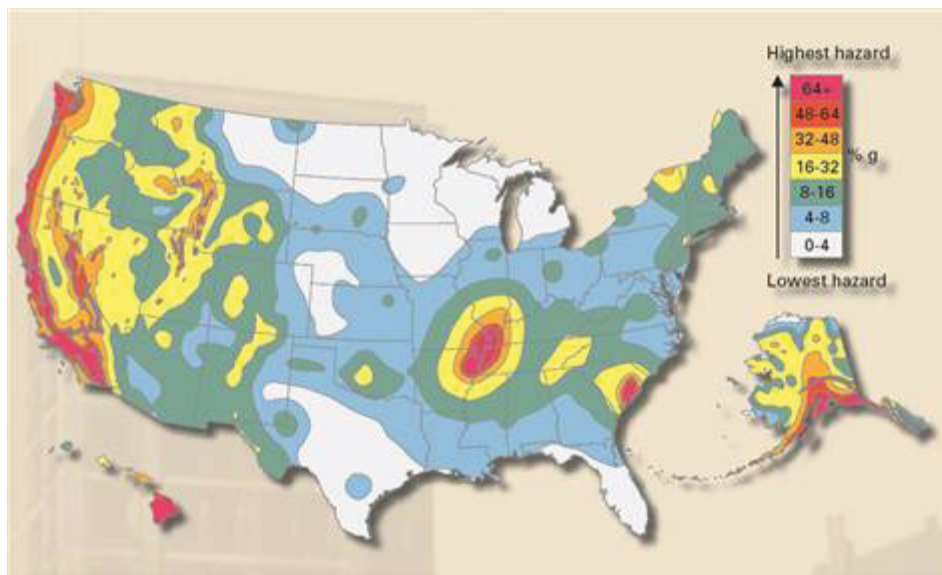
The NRC, the federal agency responsible for nuclear power safety, says the odds are in the public's favor. "Operating nuclear power plants are safe," the NRC said when it reported the new risk estimates.

Every plant is designed with a margin of safety beyond the strongest earthquake anticipated in that area, the NRC says.

But the NRC also says the margin of safety has been reduced.

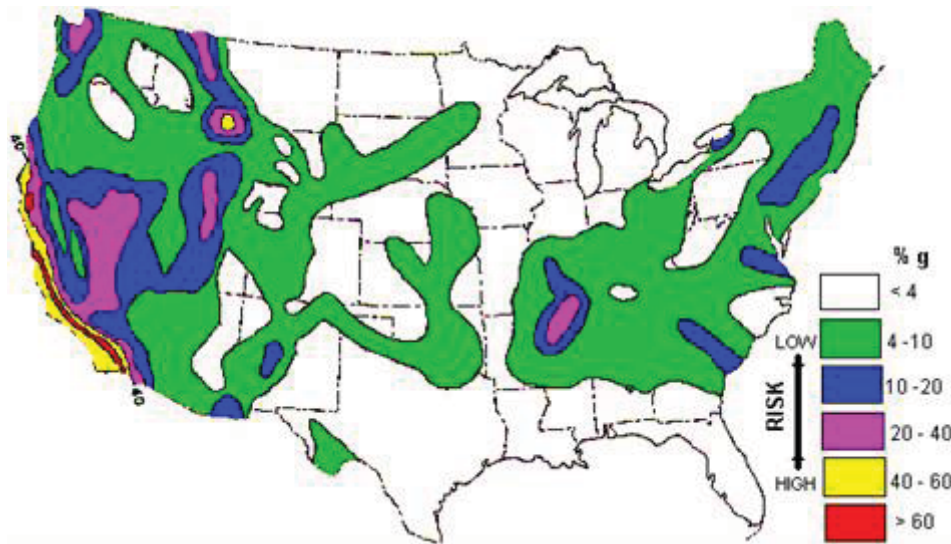
Update: The NRC on March 19 released answers to frequently asked questions about risks to U.S. nuclear plants from earthquake or tsunami. [PDF file.](#)

In the 35 years since Indian Point 3 got its license to operate in 1976, the same era when most of today's U.S. nuclear reactors were built, geologists have learned a lot about the dangers of earthquakes in the eastern and central U.S.



U.S. Geological Survey

Based on 2008 data, a map of earthquake damage risk in the United States. The highest risk areas are purple, red and orange.



U.S. Geological Survey

Based on 1982 data, a map of earthquake damage risk in the continental United States. The highest risk areas are red, yellow and purple.

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No one alive now has memories of the South Carolina quakes of 1886, which toppled 14,000 chimneys in Charleston and were felt in 30 states. Or the New Madrid quakes of 1811-1812 in Missouri and Arkansas — the big one made the Mississippi River run backward for a time.

But the geologists and seismologists remember, learning their history from rocks, and steadily raising their estimates of the risk of severe quakes. New faults are found, and new computer models change predictions for how the ground shakes. The latest estimates are drawn from the 2008 maps of the U.S. Geological Survey. Of special note, the USGS said, was an allowance for waves of large earthquakes in the New Madrid fault area roughly centered on the Missouri Bootheel, as well as inclusion of offshore faults near Charleston, S.C., and new data from the mountains of East Tennessee. With each new map, the areas of negligible risks have receded.

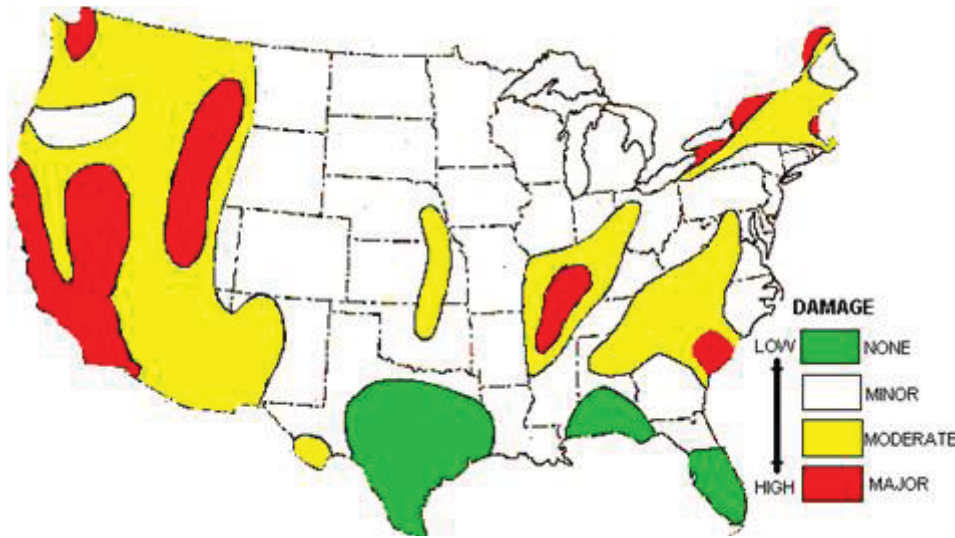
Based on those new maps, the NRC published in August 2010 new estimates of the earthquake risk at nuclear power reactors in the eastern and central states. Besides the proximity, severity and frequency of earthquakes, the new estimates take into account the design standards used at each plant, along with the type of rock or soil it's built on. This week, the NRC provided additional data to msnbc.com for the relatively few reactors in the Western states, allowing a ranking to be made of all 104 reactors with the latest data.

The top 10

Here are the 10 nuclear power sites with the highest risk of an earthquake causing core damage, showing their NRC risk estimates based on 2008 and 1989 geological data.

1. Indian Point 3, Buchanan, N.Y.: 1 in 10,000 chance each year. Old estimate: 1 in 17,241. Increase in risk: 72 percent.
2. Pilgrim 1, Plymouth, Mass.: 1 in 14,493. Old estimate: 1 in 125,000. Increase in risk: 763 percent.
3. Limerick 1 and 2, Limerick, Pa.: 1 in 18,868. Old estimate: 1 in 45,455. Increase in risk: 141 percent.
4. Sequoyah 1 and 2, Soddy-Daisy, Tenn.: 1 in 19,608. Old estimate: 1 in 102,041. Increase in risk: 420 percent.
5. Beaver Valley 1, Shippingport, Pa.: 1 in 20,833. Old estimate: 1 in 76,923. Increase in risk: 269 percent.
6. Saint Lucie 1 and 2, Jensen Beach, Fla.: 1 in 21,739. Old estimate: N/A.
7. North Anna 1 and 2, Louisa, Va.: 1 in 22,727. Old estimate: 1 in 31,250. Increase in risk: 38 percent.
8. Oconee 1, 2 and 3, Seneca, S.C.: 1 in 23,256. Old estimate: 1 in 100,000. Increase in risk: 330 percent.
9. Diablo Canyon 1 and 2, Avila Beach, Calif.: 1 in 23,810. Old estimate: N/A.
10. Three Mile Island, Middletown, Pa.: 1 in 25,000. Old estimate: 1 in 45,455. Increase in risk: 82 percent.

(This short list of the top 10 sites, or plants, groups together reactors at the same site if they have the same risk rating, such as Sequoyah 1 and 2. The full list of 104 separate reactors is below at the bottom of the text.)



U.S. Geological Survey

Based on 1969 data, a map of earthquake damage risk in the continental United States. The highest risk areas are red and yellow.

A rising risk

Northeast of Chattanooga, Tenn., the Tennessee Valley Authority's Sequoyah 1 and 2 nuclear plants had been thought to have a risk of core damage from an earthquake happening once every 102,041 years.

The new estimate is once every 19,608 years.

That kind of change was typical. Out of 104 reactors, the risk estimate declined at only eight. (There were 19 for which no older estimate was available for comparison.)

The increase in risk is so rapid that an NRC research task force in September sent two recommendations to NRC management:

First, it is time to move the issue over from the research staff to the regulatory staff, moving from study to action.

Second, start figuring out whether some nuclear power plants need a "backfit," or additional construction to protect them from earthquakes.

Another indication of how fast the risk estimates rose: The median, or middle value out of all 104 reactors, a measure of the risk at the typical plant, is now at a 1 in 74,176 chance each year of core damage from a quake. In the old estimate, it was 1 in 263,158. In other words, the estimated risk, though still low by NRC standards, has more than tripled.

What happens next?

This NRC process began in 2005 when its staff recommended taking a look at updated seismic hazards. It was late 2008 before NRC staff started working with a contractor, Electric Power Research Institute, on the design of a study. Overall, it took five years and three months from the staff recommendation until the seismic task force submitted its report in August 2010.

One problem is a lack of data about the nuclear reactors themselves. The NRC task force said the agency has detailed data on what it calls plant fragility — the probability that the expected earthquake would damage the reactor's core — for only one-third of the nation's nuclear plants. That's because only the plants that had been thought to be in areas of higher seismic risk had done detailed studies. For the rest, the scientists had to estimate from other information submitted by plant operators.

Now the NRC is playing catch-up.

An NRC spokesman, Scott Burnell, said Tuesday that the NRC is preparing a letter to send to certain nuclear plants, asking them for the more detailed data on equipment, soil conditions and seismic preparedness. Then the plants and NRC staff will have an opportunity to analyze that data.

That process could stretch into 2012, Burnell said. Then the NRC will have to decide, he said, "where the ability to respond to seismic events can be improved."

In the middle of that process, perhaps late this year, a new round of geologic data will come out. That will be folded into new calculations.

Industry is "addressing that issue"

The nuclear power industry is watching this process. A document distributed to the public by the industry's Nuclear Energy Institute on Sunday, after the Japanese plant emergency began, referred to this NRC study and the possibility of changes, saying, "The industry is working with the NRC to develop a methodology for addressing that issue."

The industry statement did not mention that the study increased the estimates of earthquake risk for nearly every nuclear power plant in the U.S.

(One of the leading nuclear power companies, General Electric, which designed the reactors at Fukushima, is a part owner of NBCUniversal, which co-owns msnbc.com through a joint venture with Microsoft.)

Good odds or bad?

How much risk is too much? Is a roller coaster safe only if no one ever dies? If one passenger dies every 100 years? Every year?

When the NRC saw that the new earthquake maps had pushed the level of risk into the range between 1 in 100,000 and the more likely 1 in 10,000, that change was enough to study the issue further, the task force said in its report. But because the risks didn't go beyond 1 in 10,000, "there was no immediate concern regarding adequate protection." The new estimates put Indian Point right at that boundary, and a few others in reach.

By comparison, the chance of winning the grand prize in the next Powerball lottery: 1 in 195,249,054.

Ranking of nuclear reactors by earthquake damage risks

Here are the 104 nuclear power reactors in the United States, ranked by the NRC's estimate of the risk each year that an earthquake would cause damage to the reactor's core, possibly releasing radiation.

Notes: Data come from the NRC's study of August 2010 on reactors in the central and eastern states, supplemented by data provided by the NRC to msnbc.com in March 2011. The table shows the risks calculated separately from 1989 and 2008 earthquake data from the U.S. Geological Survey. Ranks and changes in risk are calculated by msnbc.com. For the reactors in the western states, and a few others, the 1989 estimate was not provided to msnbc.com, so no change is calculated. The information in this list is also available in an Excel spreadsheet file. (See resources, below.)

Rank. Reactor, nearby city, state: Chance each year of core damage from an earthquake, showing NRC estimates based on 2008 USGS data. Old estimate from 1989 data. Change in risk.

1. Indian Point 3, Buchanan, N.Y.: 1 in 10,000 chance each year. Old estimate: 1 in 17,241. Change in risk: 72 percent.

2. Pilgrim 1, Plymouth, Mass.: 1 in 14,493 chance each year. Old estimate: 1 in 125,000. Change in risk: 763 percent.

3. Limerick 1, Limerick, Pa.: 1 in 18,868 chance each year. Old estimate: 1 in 45,455. Change in risk: 141 percent.

3. Limerick 2, Limerick, Pa.: 1 in 18,868 chance each year. Old estimate: 1 in 45,455. Change in risk: 141 percent.

5. Sequoyah 1, Soddy-Daisy, Tenn.: 1 in 19,608 chance each year. Old estimate: 1 in 102,041. Change in risk: 420 percent.

5. Sequoyah 2, Soddy-Daisy, Tenn.: 1 in 19,608 chance each year. Old estimate: 1 in 102,041. Change in risk: 420 percent.

7. Beaver Valley 1, Shippingport, Pa.: 1 in 20,833 chance each year. Old estimate: 1 in 76,923. Change in risk: 269 percent.

8. Saint Lucie 1, Jensen Beach, Fla.: 1 in 21,739 chance each year. Old estimate: N/A. Change in risk: N/A.

8. Saint Lucie 2, Jensen Beach, Fla.: 1 in 21,739 chance each year. Old estimate: N/A. Change in risk: N/A.

10. North Anna 1, Louisa, Va.: 1 in 22,727 chance each year. Old estimate: 1 in 31,250. Change in risk: 38 percent.

10. North Anna 2, Louisa, Va.: 1 in 22,727 chance each year. Old estimate: 1 in 31,250. Change in risk: 38 percent.

12. Oconee 1, Seneca, S.C.: 1 in 23,256 chance each year. Old estimate: 1 in 100,000. Change in risk: 330 percent.

12. Oconee 2, Seneca, S.C.: 1 in 23,256 chance each year. Old estimate: 1 in 100,000. Change in risk: 330 percent.

12. Oconee 3, Seneca, S.C.: 1 in 23,256 chance each year. Old estimate: 1 in 100,000. Change in risk: 330 percent.

15. Diablo Canyon 1, Avila Beach, Calif.: 1 in 23,810 chance each year. Old estimate: N/A. Change in risk: N/A.

15. Diablo Canyon 2, Avila Beach, Calif.: 1 in 23,810 chance each year. Old estimate: N/A. Change in risk: N/A.

17. Three Mile Island 1, Middletown, Pa.: 1 in 25,000 chance each year. Old estimate: 1 in 45,455.
Change in risk: 82 percent.
18. Palo Verde 1, Wintersburg, Ariz.: 1 in 26,316 chance each year. Old estimate: N/A. Change in risk:
N/A.
18. Palo Verde 2, Wintersburg, Ariz.: 1 in 26,316 chance each year. Old estimate: N/A. Change in risk:
N/A.
18. Palo Verde 3, Wintersburg, Ariz.: 1 in 26,316 chance each year. Old estimate: N/A. Change in risk:
N/A.
18. Summer, Jenkinsville, S.C.: 1 in 26,316 chance each year. Old estimate: 1 in 138,889. Change in
risk: 428 percent.
22. Catawba 1, York, S.C.: 1 in 27,027 chance each year. Old estimate: 1 in 33,333. Change in risk: 23
percent.
22. Catawba 2, York, S.C.: 1 in 27,027 chance each year. Old estimate: 1 in 33,333. Change in risk: 23
percent.
24. Watts Bar 1, Spring City, Tenn.: 1 in 27,778 chance each year. Old estimate: 1 in 178,571. Change in
risk: 543 percent.
25. Indian Point 2, Buchanan, N.Y.: 1 in 30,303 chance each year. Old estimate: 1 in 71,429. Change in
risk: 136 percent.
26. Duane Arnold, Palo, Iowa: 1 in 31,250 chance each year. Old estimate: N/A. Change in risk: N/A.
27. McGuire 1, Huntersville, N.C.: 1 in 32,258 chance each year. Old estimate: 1 in 35,714. Change in
risk: 11 percent.
27. McGuire 2, Huntersville, N.C.: 1 in 32,258 chance each year. Old estimate: 1 in 35,714. Change in
risk: 11 percent.
29. Farley 1, Columbia, Ala.: 1 in 35,714 chance each year. Old estimate: 1 in 263,158. Change in risk:
637 percent.

29. Farley 2, Columbia, Ala.: 1 in 35,714 chance each year. Old estimate: 1 in 263,158. Change in risk: 637 percent.

31. Quad Cities 1, Cordova, Ill.: 1 in 37,037 chance each year. Old estimate: 1 in 71,429. Change in risk: 93 percent.

31. Quad Cities 2, Cordova, Ill.: 1 in 37,037 chance each year. Old estimate: 1 in 71,429. Change in risk: 93 percent.

33. River Bend 1, St. Francisville, La.: 1 in 40,000 chance each year. Old estimate: 1 in 370,370. Change in risk: 826 percent.

34. Peach Bottom 2, Delta, Pa.: 1 in 41,667 chance each year. Old estimate: 1 in 120,482. Change in risk: 189 percent.

34. Peach Bottom 3, Delta, Pa.: 1 in 41,667 chance each year. Old estimate: 1 in 120,482. Change in risk: 189 percent.

36. Crystal River 3, Crystal River, Fla.: 1 in 45,455 chance each year. Old estimate: 1 in 192,308. Change in risk: 323 percent.

36. Seabrook 1, Seabrook, N.H.: 1 in 45,455 chance each year. Old estimate: 1 in 114,943. Change in risk: 153 percent.

36. Beaver Valley 2, Shippingport, Pa.: 1 in 45,455 chance each year. Old estimate: 1 in 188,679. Change in risk: 315 percent.

39. Perry 1, Perry, Ohio: 1 in 47,619 chance each year. Old estimate: 1 in 1,176,471. Change in risk: 2371 percent.

39. Columbia 1, Richland, Wash.: 1 in 47,619 chance each year. Old estimate: N/A. Change in risk: N/A.

41. Waterford 3, Killona, La.: 1 in 50,000 chance each year. Old estimate: 1 in 833,333. Change in risk: 1567 percent.

42. Dresden 2, Morris, Ill.: 1 in 52,632 chance each year. Old estimate: 1 in 434,783. Change in risk: 726 percent.

42. Dresden 3, Morris, Ill.: 1 in 52,632 chance each year. Old estimate: 1 in 434,783. Change in risk: 726 percent.

42. Monticello, Monticello, Minn.: 1 in 52,632 chance each year. Old estimate: 1 in 38,462. Change in risk: -27 percent.

45. Wolf Creek 1, Burlington, Kansas: 1 in 55,556 chance each year. Old estimate: 1 in 400,000. Change in risk: 620 percent.

46. San Onofre 2, San Clemente, Calif.: 1 in 58,824 chance each year. Old estimate: N/A. Change in risk: N/A.

46. San Onofre 3, San Clemente, Calif.: 1 in 58,824 chance each year. Old estimate: N/A. Change in risk: N/A.

48. Millstone 3, Waterford, Conn.: 1 in 66,667 chance each year. Old estimate: 1 in 100,000. Change in risk: 50 percent.

48. Brunswick 1, Southport, N.C.: 1 in 66,667 chance each year. Old estimate: 1 in 263,158. Change in risk: 295 percent.

48. Brunswick 2, Southport, N.C.: 1 in 66,667 chance each year. Old estimate: 1 in 263,158. Change in risk: 295 percent.

48. Robinson 2, Hartsville, S.C.: 1 in 66,667 chance each year. Old estimate: 1 in 370,370. Change in risk: 456 percent.

52. Oyster Creek, Forked River, N.J.: 1 in 71,429 chance each year. Old estimate: 1 in 126,582. Change in risk: 77 percent.

53. Fort Calhoun, Fort Calhoun, Neb.: 1 in 76,923 chance each year. Old estimate: N/A. Change in risk: N/A.

53. Ginna, Ontario, N.Y.: 1 in 76,923 chance each year. Old estimate: 1 in 238,095. Change in risk: 210 percent.

53. Susquehanna 1, Salem Township, Pa.: 1 in 76,923 chance each year. Old estimate: 1 in 416,667. Change in risk: 442 percent.

53. Susquehanna 2, Salem Township, Pa.: 1 in 76,923 chance each year. Old estimate: 1 in 416,667. Change in risk: 442 percent.

57. Calvert Cliffs 2, Lusby, Md.: 1 in 83,333 chance each year. Old estimate: 1 in 116,279. Change in risk: 40 percent.

57. D.C. Cook 1, Bridgman, Mich.: 1 in 83,333 chance each year. Old estimate: N/A. Change in risk: N/A.

57. D.C. Cook 2, Bridgman, Mich.: 1 in 83,333 chance each year. Old estimate: N/A. Change in risk: N/A.

57. Grand Gulf 1, Port Gibson, Miss.: 1 in 83,333 chance each year. Old estimate: 1 in 106,383. Change in risk: 28 percent.

57. Kewaunee, Kewaunee, Wis.: 1 in 83,333 chance each year. Old estimate: 1 in 71,429. Change in risk: -14 percent.

62. Millstone 2, Waterford, Conn.: 1 in 90,909 chance each year. Old estimate: 1 in 156,250. Change in risk: 72 percent.

62. Salem 1, Hancocks Bridge, N.J.: 1 in 90,909 chance each year. Old estimate: 1 in 172,414. Change in risk: 90 percent.

62. Salem 2, Hancocks Bridge, N.J.: 1 in 90,909 chance each year. Old estimate: 1 in 172,414. Change in risk: 90 percent.

62. Point Beach 1, Two Rivers, Wis.: 1 in 90,909 chance each year. Old estimate: 1 in 76,923. Change in risk: -15 percent.

62. Point Beach 2, Two Rivers, Wis.: 1 in 90,909 chance each year. Old estimate: 1 in 76,923. Change in risk: -15 percent.

67. Turkey Point 3, Homestead, Fla.: 1 in 100,000 chance each year. Old estimate: N/A. Change in risk: N/A.

67. Turkey Point 4, Homestead, Fla.: 1 in 100,000 chance each year. Old estimate: N/A. Change in risk: N/A.

67. Calvert Cliffs 1, Lusby, Md.: 1 in 100,000 chance each year. Old estimate: 1 in 142,857. Change in risk: 43 percent.

70. Vermont Yankee, Vernon, Vt.: 1 in 123,457 chance each year. Old estimate: 1 in 434,783. Change in risk: 252 percent.

71. Braidwood 1, Braceville, Ill.: 1 in 136,986 chance each year. Old estimate: 1 in 1,785,714. Change in risk: 1204 percent.

71. Braidwood 2, Braceville, Ill.: 1 in 136,986 chance each year. Old estimate: 1 in 1,785,714. Change in risk: 1204 percent.

73. Vogtle 1, Waynesboro, Ga.: 1 in 140,845 chance each year. Old estimate: 1 in 384,615. Change in risk: 173 percent.

73. Vogtle 2, Waynesboro, Ga.: 1 in 140,845 chance each year. Old estimate: 1 in 384,615. Change in risk: 173 percent.

75. Cooper, Brownville, Neb.: 1 in 142,857 chance each year. Old estimate: N/A. Change in risk: N/A.

76. Davis-Besse, Oak Harbor, Ohio: 1 in 149,254 chance each year. Old estimate: 1 in 625,000. Change in risk: 319 percent.

77. Palisades, Covert, Mich.: 1 in 156,250 chance each year. Old estimate: N/A. Change in risk: N/A.

78. South Texas 1, Bay City, Texas: 1 in 158,730 chance each year. Old estimate: 1 in 1,298,701. Change in risk: 718 percent.

78. South Texas 2, Bay City, Texas: 1 in 158,730 chance each year. Old estimate: 1 in 1,298,701. Change in risk: 718 percent.

80. FitzPatrick, Scriba, N.Y.: 1 in 163,934 chance each year. Old estimate: 1 in 833,333. Change in risk: 408 percent.

81. Byron 1, Byron, Ill.: 1 in 172,414 chance each year. Old estimate: 1 in 1,470,588. Change in risk: 753 percent.

81. Byron 2, Byron, Ill.: 1 in 172,414 chance each year. Old estimate: 1 in 1,470,588. Change in risk: 753 percent.

83. Surry 1, Surry, Va.: 1 in 175,439 chance each year. Old estimate: 1 in 123,457. Change in risk: -30 percent.

83. Surry 2, Surry, Va.: 1 in 175,439 chance each year. Old estimate: 1 in 123,457. Change in risk: -30 percent.

85. Nine Mile Point 2, Scriba, N.Y.: 1 in 178,571 chance each year. Old estimate: 1 in 1,000,000. Change in risk: 460 percent.

86. Browns Ferry 2, Athens, Ala.: 1 in 185,185 chance each year. Old estimate: 1 in 625,000. Change in risk: 238 percent.

86. Browns Ferry 3, Athens, Ala.: 1 in 185,185 chance each year. Old estimate: 1 in 625,000. Change in risk: 238 percent.

88. Nine Mile Point 1, Scriba, N.Y.: 1 in 238,095 chance each year. Old estimate: 1 in 1,724,138. Change in risk: 624 percent.

88. Fermi 2, Monroe, Mich.: 1 in 238,095 chance each year. Old estimate: 1 in 625,000. Change in risk: 163 percent.

90. Arkansas Nuclear 1, London, Ark.: 1 in 243,902 chance each year. Old estimate: 1 in 1,063,830. Change in risk: 336 percent.

90. Arkansas Nuclear 2, London, Ark.: 1 in 243,902 chance each year. Old estimate: 1 in 1,063,830. Change in risk: 336 percent.

92. Comanche Peak 1, Glen Rose, Texas: 1 in 250,000 chance each year. Old estimate: 1 in 833,333. Change in risk: 233 percent.

92. Comanche Peak 2, Glen Rose, Texas: 1 in 250,000 chance each year. Old estimate: 1 in 833,333. Change in risk: 233 percent.

94. Browns Ferry 1, Athens, Ala.: 1 in 270,270 chance each year. Old estimate: 1 in 1,000,000. Change in risk: 270 percent.

95. Prairie Island 1, Welch, Minn.: 1 in 333,333 chance each year. Old estimate: 1 in 714,286. Change in risk: 114 percent.

95. Prairie Island 2, Welch, Minn.: 1 in 333,333 chance each year. Old estimate: 1 in 714,286. Change in risk: 114 percent.

97. La Salle 1, Marseilles, Ill.: 1 in 357,143 chance each year. Old estimate: 1 in 1,851,852. Change in risk: 419 percent.

97. La Salle 2, Marseilles, Ill.: 1 in 357,143 chance each year. Old estimate: 1 in 1,851,852. Change in risk: 419 percent.

97. Hope Creek 1, Hancocks Bridge, N.J.: 1 in 357,143 chance each year. Old estimate: 1 in 909,091. Change in risk: 155 percent.

100. Clinton, Clinton, Ill.: 1 in 400,000 chance each year. Old estimate: 1 in 370,370. Change in risk: -7 percent.

101. Shearon Harris 1, New Hill, N.C.: 1 in 434,783 chance each year. Old estimate: 1 in 277,778. Change in risk: -36 percent.

102. Hatch 1, Baxley, Ga.: 1 in 454,545 chance each year. Old estimate: 1 in 1,351,351. Change in risk: 197 percent.

102. Hatch 2, Baxley, Ga.: 1 in 454,545 chance each year. Old estimate: 1 in 1,351,351. Change in risk: 197 percent.

104. Callaway, Fulton, Mo.: 1 in 500,000 chance each year. Old estimate: N/A. Change in risk: N/A.

A few words about the data (Where's Richter?)

The NRC's risk estimates are not based on the usual layman's language of the magnitude scale (the old

Richter scale or its replacement, the moment magnitude scale). Magnitude shows the earthquake's energy released. That is a measure of power.

How much radiation is dangerous?

1. Radiation is measured using the unit sievert, which quantifies the amount of radiation absorbed by human tissues. One sievert is 1,000 millisieverts (mSv).

In the U.S., the average person is exposed to about 6.2 millisieverts a year, mostly from background radiation and medical tests.

Facts about radiation exposure:

- A person would need to be exposed to at least 100 mSv a year to have an increase in cancer risk. Exposure to 1,000 mSv during a year would probably cause a fatal cancer many years later in five out of every 100 people.
- Total body CT scan: about 10 mSv.
- Mammogram: about 0.7 mSv.
- CT colonography: about 5 to 8 mSv.
- CT heart scan: about 12 mSv.
- Typical chest X-ray: about 0.02 mSv
- Dental X-ray: 0.01 mSv.
- Coast-to-coast airplane flight: about .03 mSv. Airline crews flying the New York-Tokyo polar route are exposed to 9 mSv a year.

Sources: Reuters; New England Journal of Medicine; American Cancer Society; World Nuclear Association and Taiwan's Atomic Energy Council

But a nuclear plant may be close to the epicenter of a quake, or far from it. And some types of seismic waves are more jarring than others.

Instead, these risk estimates consider how violently the ground will shake at the nuclear plant, considered a better indication of how much damage it will cause. That shaking can be affected by the depth, distance from the epicenter, and the frequencies of waves that the quake emits. The shaking is expressed in a unit called peak ground acceleration, in terms of the acceleration caused by the Earth's gravity. This is a measure of intensity.

Often these two ways of measuring earthquakes are roughly in synch, but sometimes not. For example:

- The 2010 Haiti earthquake, magnitude 7.0, rated only "severe" on the intensity scale, the third rung from the top, with peak ground acceleration of 0.5 times the Earth's gravity.
- The 2010 Chile earthquake, with a much higher magnitude of 8.8, was one step higher in terms of intensity, "violent," with peak ground acceleration of 0.65 times gravity.
- The 2010 Christchurch or Canterbury earthquake in New Zealand, similar to Haiti at magnitude 7.1, was at the top of the intensity scale, "extreme," with a peak ground acceleration of 1.26 times gravity.

Besides the peak acceleration, the NRC made other estimates for each nuclear plant, based on different types of earthquakes.

From all these estimates, the NRC calculated a worst case, which it called the "weakest link." Msnbc.com ranked the plants by that worst case, which is the same number the NRC staff highlights in its report, and the only number it provided for the reactors in the western states.

Resources

These links open in a new window.

NRC [answers to frequently asked questions](#) on earthquake and tsunami risk. PDF file.

[Earthquake history of each state](#), from the USGS.

A USGS brochure describing the [changes in the 2008 seismic hazard maps](#). PDF file.

The [NRC report with new earthquake risk estimates](#), "Generic Issue 199 (GI-199), Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States on Existing Plants, Safety/Risk Assessment," August 2010. PDF file. Note: Data for individual reactors are in appendix D.

An [NRC fact sheet](#) from November 2010, "Seismic Issues for Existing Nuclear Power Plants."

The NRC [database of active nuclear reactors](#) in the U.S. Each reactor name links to technical and safety documents.

[Industry response to questions](#) about the situation in Japan. PDF file.

A scientific paper describing [the New Madrid earthquake](#), and what can be learned by melding modern science with writings from long ago.

A brochure with a table comparing values for [magnitude and peak ground acceleration](#).

The ranking of 104 nuclear plants by risk, by msnbc.com from NRC data, in an [Excel spreadsheet file](#).

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