The Mystery of the Missing Bolts:
New York City's Stricken Indian Point Nuclear Plant

A collaboration between Friends of the Earth and Fairewinds Associates, Inc

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Executive Summary

"Missing bolts" and "nuclear reactor" are words one generally does not want to see in the same sentence. And when the missing bolts are many, the risk and concern multiply.

In the case of the Indian Point nuclear power plant just outside of New York City, the risk is that the missing bolts will cause the nuclear reactors to overheat, meltdown and release deadly radioactivity over the surrounding population and countryside. Specifically, leaks due to the missing bolts could deprive the reactor of sufficient cooling water to contain the 550 degrees Fahrenheit temperature in the reactor's nuclear fuel, triggering an uncontrollable nuclear meltdown with catastrophic results from temperatures reaching more than 2,000 degrees. More than one out of every four bolts that help channel cooling water to the Indian Point Unit 2 reactor is currently damaged or missing, according to an inspection by the plant's owner Entergy. This is an extraordinarily high failure rate that appears to be unprecedented in the history of the global nuclear power industry.

Indian Point reactor Unit 2—and its twin "sister," Indian Point 3—are located 26 miles north of New York City, along the east side of the Hudson River. Depending on the speed and direction of the wind, any radioactivity escaping from Indian Point could easily reach New York's Times Square within 90 minutes, making mass evacuation impossible.

This situation demands immediate remedy.

This collaborative report aims to urge and inform a viable solution. It offers recommendations and specific actions that should be taken by Entergy (the corporate owner of Indian Point) by state government, and especially by federal regulators, the Nuclear Regulatory Commission (NRC).

New York Governor Andrew Cuomo, citing a string of previous safety concerns at Indian Point, has been calling for the plant's closure since his tenure as the state's attorney general from 2006 to 2010. At a minimum, the current episode signals for Indian Point Unit 2 to remain off-line until the *Mystery of the Missing Bolts* is fully investigated, analyzed and totally corrected, if correction is even possible. Because Indian Point Unit 3 is, technically speaking, virtually identical to its sister reactor, Indian Point Unit 3 should also be taken off-line immediately to undergo a rigorous independent investigation before being allowed to operate again. With 20 million people across three states living within 50 miles of Indian Point, any risk of a nuclear accident is unconscionable.

To explain why such a strong response is necessary, this collaborative report begins by describing how the missing bolts were discovered. It notes that some of the bolts in question are outright missing while others are broken or damaged. The report observes that the 27.2 percent failure rate of the reactor bolts at Indian Point Unit 2 appears to be unprecedented at a global scale, and it explains in layperson's terms why such a widespread absence of bolts poses extraordinary danger to the reactor and therefore the public.

The Mystery of the Missing Bolts: A Brief History

The missing bolts at Indian Point Unit 2 were discovered in a March 2016 inspection that the state of New York insisted upon over repeated objections from Entergy.

Entergy took ownership of the Indian Point Unit 2 and Unit 3 reactors in 2001. The plants were built in the early 1970s by Consolidated Edison, the utility company that distributes electricity to much of New York City and its northern neighbor, Westchester County. The reactors occupy what Entergy calls the Indian Point Energy Center, which is located roughly 26 miles from New York City limits and only 36 miles from midtown Manhattan, along the eastern side of the Hudson River in the town of Buchanan, New York.

Indian Point Unit 2 and Indian Point Unit 3 are large power plants that generate a sizable amount of electricity. Historically, the two nuclear reactors have generated around 10 percent of New York's power. Indian Point Unit 2 has a generating capacity of 1,032 megawatts (MW); Indian Point Unit 3, a generating capacity of 1,051 MW.

From their beginning, the Indian Point nuclear reactors have experienced a string of major and minor safety problems. Five months after Indian Point Unit 2 opened, it was closed to repair a faulty containment dome, the structure designed to prevent radioactivity from escaping in the event of a reactor meltdown. Often as a result of fires, electrical transformers in particular have malfunctioned at Indian Point, unleashing toxic liquid into the Hudson River. As recently as 2013, a veteran former supervisor at Indian Point was arrested and charged with falsifying safety reports and lying to federal regulators.

The recurring safety lapses at Indian Point, and the apparent laxness on the part of its owner Entergy, led state and local officials, environmental organizations and ordinary citizens to demand better. Andrew Cuomo called Indian Point "a catastrophe waiting to happen" and called for the plant to be shut down in 2007 while serving as the attorney general of New York. As governor, Cuomo has continued to urge closure of the entire complex. Meanwhile, the Cuomo administration continues to closely monitor developments and pushes corporate owner Entergy and the NRC to be more vigilant.

In particular, the Cuomo administration has demanded a thorough safety inspection before the NRC rules on whether to allow Indian Point Units 2 and 3 to continue operating past the plants' original 40-year operating licenses. Those licenses expired in 2013 and 2015, respectively. Like any industrial facility, a nuclear plant encounters issues as it ages: parts wear out, scientific advances counsel different approaches to issues such as earthquakes. Challenges of aging are especially acute for nuclear reactors, because of the extraordinary stresses imposed by the high temperatures, neutron bombardment, and extreme water pressure inside a reactor.

The Governor pressed the Nuclear Regulatory Commission to require inspections of the baffle-former bolts in the Indian Point reactors. At the insistence of the Governor, Entergy did undertake inspections commencing on March 7, 2016.

The results of the Indian Point inspection confirmed the Cuomo administration's fears. Entergy reported its findings in a March 29 report to the NRC's Atomic Safety and Licensing Board Panel, a group of three nuclear specialists who conduct public hearings and rule on the licensing and operation of US nuclear plants. Entergy declared that its inspectors discovered that 227 of the bolts that surround the Indian Point Unit 2 reactor were either missing or damaged.

The bolts at issue are critical safety components that go by the awkward name of "baffle-former assembly bolts." They hold in place metal plates—baffles—that channel cooling water through the reactor, providing essential protection against the possibility of over-heating. A quarter of a million gallons of cooling water flows through the core of the Indian Point Unit 2 reactor every minute it operates. The baffles assure that this cooling water enters and leaves the reactor core in the proper amount, timing and velocity. If enough bolts are missing, the baffles may slip and these vital safety functions would be interrupted. See figure below.

Figure 1 shows Fairewinds Associates' Chief Engineer at a full-scale mockup of a Westinghouse nuclear reactor similar to Indian Point Unit 2. The reactor's emergency cooling water, depicted in blue, enters at the upper-left corner. When the baffle bolts and other reactor internals are functioning properly, the water descends along the outside of the reactor's "core barrel" to the base of the reactor. It then moves uniformly upward through the nuclear core, keeping the core temperature in the safety zone, before exiting the reactor at top right.

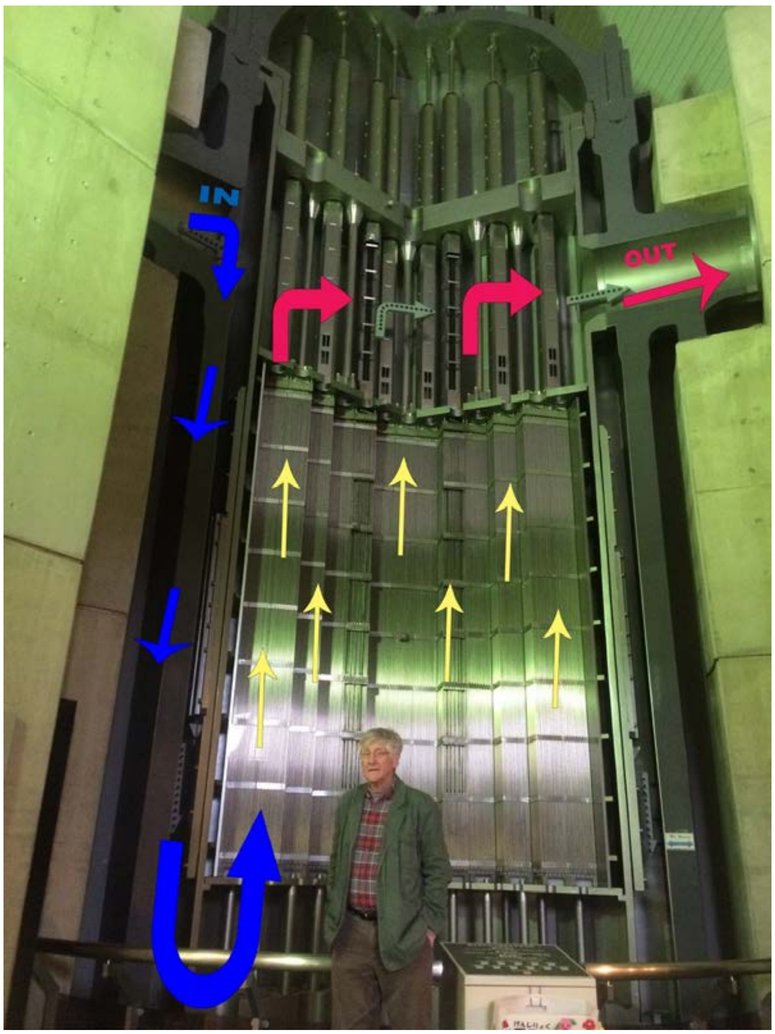
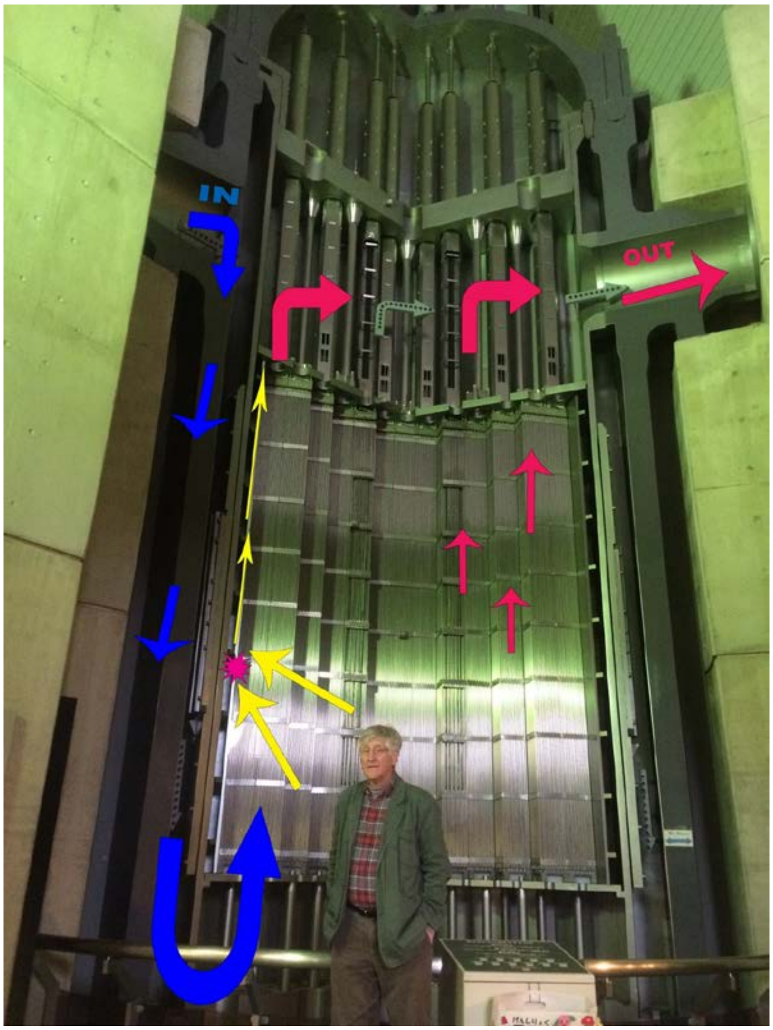


Figure 2 illustrates how missing or damaged baffle bolts can cause the reactor to overheat. If the bolts fail, the plates will open, allowing the cooling water to deviate from its normally tightly constrained path through the reactor, risking overheating of the reactor core and an uncontrollable nuclear reaction and meltdown.



The Indian Point Unit 2 nuclear reactor was designed to rely on a total of 832 baffle-former assembly bolts. Finding that 227 of these bolts were either missing or damaged meant that 27.2 percent of the reactor's baffle-former assembly bolts were defective. No other Westinghouse Pressurized Water Reactor has ever reported even half that failure rate.

Instead, Entergy tried to portray an entirely different situation. Presenting the glass as half-full, Entergy's public statement after the inspection declared that only 11 percent of the roughly 2,000 bolts it had inspected were degraded. Tellingly, Entergy admitted as much in a legal filing it submitted in parallel with its public statement. With the company's legal liability on the line, its officials provided data that was, one can say, more precise. This data revealed that, in regards to the 832 "baffle-former assembly bolts" around the reactor, 227 were defective. In other words, a 27.2 percent failure rate.

As far as Fairewinds Associates can determine, this failure rate is unprecedented, not only in US reactors but globally. Not surprisingly, it also appears to violate the safety standards prescribed by the reactor's manufacturer, Westinghouse.

Westinghouse's guidance is worthy of attention. No company has a longer, deeper history in the nuclear industry than Westinghouse. In 1946, the US Navy chose Westinghouse to design and build the first reactor intended for electric generation rather than strictly military purposes; the company went on to sell more reactors, in more countries, than any other nuclear corporation. After the market for new reactors crashed in the 1970s, Westinghouse focused on servicing the existing reactor fleet—providing refueling, maintenance and repairs. Westinghouse shares Entergy's confidence that reactors and power plants originally designed to operate for 40 years can safely soldier on for decades into the future.

But aging is a reality that cannot be ignored, and Westinghouse appropriately cautions that as reactors age, attentive monitoring and careful maintenance are essential to assure proper standards of safety, efficiency and output. In a technical manual published in October 2014, Westinghouse explicitly addressed, among other issues, the role of baffle-former assembly bolts, which it called "a critical safety feature": "One component that is critical to maintaining the structural integrity of the internals [of the reactor], and that has been shown operationally to be susceptible to aging mechanisms, is the baffle-former assembly bolts." The main concern, the manual added, is that radiation from the reactor can lead to "corrosion" and "cracking" of the bolts.

Westinghouse further claimed that a "failure of a few bolts should not have a significant safety impact," because redundancy in the reactor design would keep enough bolts in place to assure safe operations. But even if one accepts this less than air-tight standard, the situation at Indian Point Unit 2 falls well short. What has failed at Indian Point Unit 2 is emphatically not just "a few bolts. *It is one out of every four*.

Most automobile drivers wouldn't get behind the wheel if they knew that one out of four bolts holding their car together was missing or broken. Why should a weaker standard apply for a nuclear reactor?

Which raises the questions, how did this happen and why was it not caught sooner? Indian Point has a "loose parts monitoring system" that is designed to detect metal bouncing within the reactor. The facts suggest that this early warning system also failed, because either there was no warning of damage or it was not reported.

What risks do the 227 missing or broken bolts present?

1. Broken pieces of metal can damage the nuclear fuel, causing it to leak and release radiation onto the surrounding environment and community, perhaps necessitating an evacuation.
2. Such metal fragments can damage the reactor's control rods, making it difficult or impossible to shut down the reactor.
3. This "floating shrapnel" can clog a fuel channel, causing the nuclear fuel to overheat, raising the potential of a meltdown.
4. The floating shrapnel can damage the impeller of the reactor coolant pumps, causing them to vibrate and develop dangerous oscillations in reactor coolant flow.
5. The 227 missing or damaged bolts could cause the baffle plates that channel cooling water into the reactor to loosen and fail, thus preventing sufficient water from reaching the reactor core, again raising the possibility of a meltdown.

How can this situation possibly be considered safe? How long has Indian Point Unit 2 been operating this way, and how can anyone be assured that it won't happen again? Is there a way to repair the reactor that can assure there will not be further, more rapid, deterioration of the remaining baffle-former bolts?

If Entergy can answer these questions persuasively, a restart of Indian Point Unit 2 might be appropriate. The plant should remain off-line until the root cause is determined, and there is assurance that the repairs are effective indefinitely and the defect will not reoccur. Without a full understanding of the root cause of bolt degradation, there can be no assurance that the remaining old bolts will not fail, nor that failure of replacement bolts will not occur. What's more, since Indian Point Unit 3 is virtually the same design and only two years younger than its sister, it should undergo the same rigorous inspection to determine whether it too has a missing or damaged bolt problem.

The NRC Must Order A Root Cause Analysis

The Nuclear Regulatory Commission is mandated by the Atomic Energy Act and its own regulations to assure the safe operability of all operating reactors in the US. The unprecedented degradation of the baffle-former bolts at Indian Point 2 poses a significantly increased risk to the safe operation of a nuclear reactor located within relatively short distances of tens of millions of Americans. Moreover, the discovery at Indian Point 2 that a quarter of the baffle-former bolts are damaged or missing raises a serious question about the potential safety of the nation's fleet of Westinghouse Pressurized Water Reactors.

Both these reasons demand that the NRC step in to assure the public of the safety of the Westinghouse nuclear reactors across the country. We therefore urge the NRC to follow established procedures and dispatch an independent Augmented Inspection Team (AIT) that can thoroughly investigate the situation inside both Indian Point Unit 2 and Indian Point Unit 3 and propose appropriate remedies. Meanwhile, the NRC should issue a Confirmatory Action Letters (CAL) requiring Indian Point Unit 2 to remain closed until the root cause of the failures in its reactor safety equipment is understood and a complete repair is completed; and a second CAL ordering the immediate shutdown of Indian Point Unit 3 for its own in-depth inspection. Until the ultimate root cause of any problem is determined at either Unit 2 or Unit 3, it is impossible to determine what may be an effective remedy, if one can even be determined and implemented.

The failure of baffle-former assembly bolts is not a new problem for the nuclear industry. The problem has been recognized since the late 1980s, as NRC Information Notice 98-11 reported in March 25, 1998:

> *European plants identified the cracking of baffle former bolts as early as 1988 and this problem continues to occur. Although **this cracking is not fully understood**, testing of cracked bolts suggests an age-related intergranular stress-corrosion cracking process influenced by bolt material, fluence, stress, and temperature.*[1] *(emphasis added)*

As worrisome as the absence of critical safety bolts at Indian Point Unit 2 is, also unsettling is

[1] http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1998/in98011.html

that no one yet knows **why** so many bolts failed. Normal wear and tear from aging is certainly plausible, but is far from the only possible explanation. Other possible causes include:

1. Improper initial torque: appropriate pressure was not applied to the wrenches when the bolts were installed.
   1.1. Thermal expansion differences between the bolt and the threaded hole it is inserted into could have reduced the torque on the bolt.
2. If this is a more recent event, the bolts could have failed due to:
   2.1. Fatigue of the bolt head from vibration due to years of exposure to rapidly flowing water.
   2.2. Damage to the bolt by the phenomena of neutron embrittlement, a metal deterioration created by the proximity of the metal to the reactor core and constant bombardment by neutrons as the reactor fuel is fissioning[2].

If and when nuclear reactors experience a missing bolts problem, Westinghouse recommends undertaking an engineering analysis that the company calls "Acceptable Baffle-former Bolt Pattern Analysis," or ABPA. Westinghouse goes so far as to assert that, with the assistance of an ABPA, a reactor can operate safely "even with many non-functional bolts." Dubious as that claim may sound to non-Westinghouse experts, including Fairewinds Associates, ABPA does enable investigators to determine the safety significance of missing bolts and to assess what remedial measures might restore acceptable safety levels. Before restart is permitted, this report should be made publicly available for independent assessment.

To conduct an ABPA investigation requires data and information that Entergy and the NRC, unfortunately, either have not obtained or have withheld from independent experts. This information includes, but is not limited to, the following:

1. A map of the distribution of the 227 missing or failed bolts.
2. Photographs of the failed and missing bolts and the threaded holes into which they were inserted so they may be analyzed for the type of damage as well as location.
3. Neutron fluence data on each missing bolt.
4. Metallurgical data on how the bolts were manufactured.

[2] Fission – "The splitting of an atom, which releases a considerable amount of energy (usually in the form of heat) that can be used to produce electricity. Fission may be spontaneous, but is usually caused by the nucleus of an atom becoming unstable (or "heavy") after capturing or absorbing a neutron. During fission, the heavy nucleus splits into roughly equal parts, producing the nuclei of at least two lighter elements. In addition to energy, this reaction usually releases gamma radiation and two or more daughter neutrons." http://www.nrc.gov/reading-rm/basic-ref/glossary/fission-fissioning.html

5. Video and reports from prior inspections that may reveal whether the component and structural failures were evident earlier.
6. Data on the bolts still in place, which might reveal why these bolts have not failed—or detect failures in the offing.
7. The extent/nature of the degradation of the 227 baffle-former bolts on IP Unit 2.
8. Whether or not there are loose parts in the reactor and, if so, why the Metal Impact Monitoring System did not detect those parts.
9. If the Metal Impact Monitoring System failed, what kind of technology-based systems and/or mechanical and structural components must be investigated, tested, and analyzed.
10. Whether all missing bolt pieces will be recovered prior to the restart of the reactor(s) and evaluated.
11. The number of degraded bolts that can be tolerated from a safety related engineering viewpoint before the integrity of the baffle-former assembly is compromised.
12. Whether some reviewers and assessors are correct that the excessive cooldown of the reactor coolant system during the February 2000 steam generator tube leak at IP Unit 2 may explain why so many baffle bolts suddenly degraded.

Entergy Has A Pattern Of Scrimping On Safety

The magnitude, complexity, and seriousness of these missing and broken baffle-former assembly bolts calls for undertaking a root cause analysis of the problem. Instead, Entergy appears to be rushing through its repairs in order to bring Indian Point Unit 2 back into operation in time for the financially lucrative summer season, when electricity demand peaks between June and October. Only the NRC can force Entergy to slow down and spend the time and money required to truly understand and appropriately respond to this situation.

Beyond the obvious motivation of limiting costs and maximizing revenue, Entergy's lack of enthusiasm for investigating the missing bolts mystery at Indian Point may reflect the company's historical approach to reactor safety. On more than one occasion, Entergy has balked at undertaking rigorous inspections of its nuclear plants. This has led, directly or indirectly, to serious mechanical problems as well as public safety risks. Here are two particularly salient examples:

Vermont Yankee

> The "Vermont Yankee Oversight Panel," a team of experts picked by Vermont's Governor and legislature, investigated Entergy's reliability to operate the Vermont Yankee nuclear power plant for 20 additional years beyond its original license period. The panel's report, issued in 2010, noted that Entergy was not spending enough money maintaining the Advanced Off-gas System (AOG) at Vermont Yankee, a failure that resulted in radioactive cesium and cobalt leaking into the ground water and the Connecticut River. The Panel further warned that insufficient safety spending by Entergy probably contributed to a fire in 2004, the collapse of a cooling tower at Vermont Yankee in 2007, and to groundwater leakage of radioactive cesium, strontium and cobalt in 2008. The Panel concluded that, "ENVY [Entergy Nuclear Vermont Yankee] management needs to assure adequate resources are allocated to the reliability of non-safety-related systems."[3]

Arkansas Nuclear One

> In 2014, workers at the Arkansas Nuclear 1 power plant inadvertently dropped a generator rotor weighing hundreds of tons, killing one employee and injuring several others. According to published reports one of the causes of this fatality was inadequate financial resources provided by Entergy: " 'Entergy Corp. made cutbacks across its fleet of nuclear power plants from 2007 through 2013 to try to remain competitive,' said Neil O'Keefe, the [NRC] branch chief responsible for oversight of Arkansas Nuclear 1…. 'It is clear that our performance experienced subtle decline from 2007 to 2013,' said Jeremy Browning, site vice president over the plant. As a result of that subtle decline, self-revealing events occurred at this [plant], resulting in a need for the NRC to intervene."[4]

Entergy is hardly unique in pursuing "quick and easy" fixes rather than the more time-consuming and costly approach of tracing evidence as far back as necessary to determine the root cause of a problem. This tendency exists to greater or lesser extents throughout the nuclear industry. The industry's history is replete with inadequate "fixes" of serious failures because reactor owners

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[3] Oversight Panel Report for the Vermont Yankee Reliability Assessment, March 2009, page iii

[4] http://www.arkansasonline.com/news/2016/apr/08/nuclear-one-staffing-played-role-in-13-/#.VwehWlkZrH0.twitter

jumped to conclusions in order to find quick, cheap fixes. Doing so did not solve the original problems, however; often, it exacerbated them.

As a result, the NRC has repeatedly failed to adequately protect public health and safety during and after major equipment failures at other reactors across the country. Three examples follow.

NRC's Past Failure to Intervene Has Worsened Nuclear Plant Issues

In the past, the NRC has too often taken the same kind of "hands-off" approach to nuclear plant safety that it has so far at Indian Point, with unfortunate results.

Quad Cities

> The Quad Cities nuclear reactor, located near Cordova, Illinois, experienced severe cracking of its steam dryer in 2002. The steam dryer is a key component inside a nuclear reactor; placed directly above the core, its function is to remove moisture from the steam that powers the generator to create electricity. Both the owner of the plant, [Exelon], and the reactor designer, [General Electric], believed that they understood the cracking problem, and that they had made appropriate repairs. The NRC reviewed the companies' calculations, did no investigation of its own, and ruled that the reactor could be restarted. One year later, the steam dryer cracked again. *Again, it was repaired and restarted, only to fail a second time.*

Millstone Unit 1

> During a refueling outage in 1973 at Millstone Unit 1, a nuclear plant located in Connecticut, visual inspection of the reactor internals revealed a long crack in a feed water sparger. A joint analysis of the failure by the reactor owner, Northeast Utilities, and the reactor manufacturer, General Electric, concluded that the problem was due to bypass leakage. This conclusion gave rise to a proposed solution, which was implemented. But one year later, during the next refueling outage, an inspection of the same feed water sparger revealed even larger cracks. It turned out the cause of the cracking had not been bypass leakage, but rather high-cycle metal fatigue, a diagnosis which lead to an entirely different solution. Neither the plant owner nor the reactor vendor had diagnosed the true cause of the cracking.

Crystal River 3

> During a steam generator replacement outage at Florida's Crystal River Unit 3 nuclear power plant, the nuclear power plant owner, at the time Progress Energy, cut a large hole into the side of the 42-inch thick concrete containment building to install replacement steam generators. The hole caused the containment to crack and delaminate. Following a year of analysis, Progress Energy proposed a repair plan to the NRC, which was implemented. However, the containment cracked and failed again one year later as the repair was being implemented. The plant owner apparently failed to correctly calculate the stress being applied to the containment structure. After four years of attempted repairs, the Crystal River Unit 3 plant was abandoned and is now being decommissioned. The financial losses to ratepayers during those four years of inadequate assessment and implementation were massive, exceeding $300,000,000 in salaries and the loss of the corporation's $2 billion asset.

As Entergy pursues a rapid restart of Indian Point Unit 2, it is failing to consider the ultimate root cause of the baffle-former bolt failure. Allowing the plant to restart before the ultimate root cause of this real operating hazard is definitively uncovered is irresponsible from both a financial and a risk perspective for the 20 million people living within 50 miles of these aged and deteriorating reactors. Likewise, continued operation of Indian Point Unit 3 while its "sister" unit exhibits severe damage is also irresponsible and an additional threat to public safety. Entergy should be required to conduct an ultimate root cause analysis and conduct the necessary repairs of both reactors before they are allowed to return to full operation.

Conclusion

As a result of New York State's persistence, inspections were finally performed at Entergy's Indian Point Unit 2 in March 2016 that uncovered 227 critical baffle-former assembly bolts that were either missing or broken. These inspections highlighted significant safety and reliability shortfalls that led Indian Point Unit 2 to remain shut for the time being. More than a quarter of the baffle-former assembly bolts, which are part of a critical safety system, are defective.

Almost two months after the Indian Point Unit 2 inspections, the cause of the broken and missing bolts remains shrouded in confusion and uncertainty. Until the *ultimate* root cause is completely understood, no effective repair can be accomplished. The magnitude of the problem and the significant safety ramifications makes it imperative that Unit 3, the exact replica of Unit 2, be immediately shut down until an inspection to determine if there any flaws within the reactor. Both reactors should remain shut down until an ultimate root cause analysis determines the cause of any damage. Additionally, the repairs for such damage must be completed prior to any thought of a possible restart.

The evidence reviewed by Fairewinds shows that the NRC should immediately implement five actions to address the critical safety problems at the Indian Point Site, which lies in such close proximity America's largest and most vulnerable city. The actions that should be implemented by the NRC are:

1. Close the loophole that allows Entergy to determine when and if Indian Point 2 restarts. To close this loophole, it is imperative that the NRC Issue a Confirmatory Action Letter (CAL) requiring the plant to remain closed until the NRC approves its restart *following an ultimate root cause evaluation that assesses the extent of the damage and delineates a complete itemized recovery plan.*
2. Mobilize a special Augmented Inspection Team (AIT) to assess the complications inside the Indian Point 2 reactor.
3. Issue a Confirmatory Action Letter requiring the immediate shutdown and inspection Indian Point Unit 3 in order to determine the amount of aging reactor damage within this replica reactor.
4. If issues are found at Indian Point Unit 3, the NRC should mobilize a second Augmented Inspection Team (AIT) to assess the complications inside Indian Point Unit 3's reactor.
5. If issues are uncovered at Indian Point Unit 3, the CAL should require the plant to remain shut, like Indian Point Unit 2, until such time the NRC approves restart *following an ultimate root cause evaluation that assesses the extent of the damage and delineates a complete itemized recovery plan*.