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Regulation, Compliance, and Proximity: Evidence from Nuclear Safety

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MARIO DANIELE AMORE*

CHLOÉ LE COQ[†]

SEBASTIAN SCHWENEN[‡]

* Bocconi University, Italy, CEPR and ECGI

[†] Université Paris-Panthéon-Assas, CRED, France and Stockholm School of Economics (SITE).

[‡] Technical University of Munich, German Institute for Economic Research DIW Berlin, and Mannheim Institute for Sustainable Energy Studies.

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Mario Daniele Amore Chloé Le Coq Sebastian Schwenen

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Abstract

Safety performance varies widely across firms, even in high-risk industries with strict regulatory standards. Using administrative data from U.S. nuclear power plants, we find that variation in safety outcomes partly reflects inspector allocation: less experienced inspectors are disproportionately assigned to facilities located farther from regional regulatory offices. This spatial sorting has meaningful economic consequences: doubling inspector experience increases staff emergency training scores by 0.3 percentage points, corresponding to avoided revenue losses of approximately USD 1.2 billion annually for the industry. These findings highlight how internal organizational dynamics within regulatory agencies can weaken the consistency and effectiveness of oversight.

JEL codes: J24, Q42, Q48

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*Amore: Bocconi University, CEPR and ECGI. Email: mario.amore@unibocconi.it. Le Coq: Paris Panthéon-Assas University (CRED) and Stockholm School of Economics (SITE). Email: chloe.le-coq@assas-universite.fr. Schwenen: Technical University of Munich, German Institute for Economic Research DIW Berlin, and Mannheim Institute for Sustainable Energy Studies. Email: sebastian.schwenen@tum.de. For helpful comments and suggestions, we thank Nicolas Astier, Elena Dumitrescu, Claude Fluet, Massimo Filippini, Christian von Hirschhausen, Mario Liebensteiner, Lena Kitzing, Christopher Knittel, Matti Liski, Geert van Moer, William Nuttal, John Parsons, Robert Ritz, Bjarne Steffen, Daniel Spiro, Björn Tyrefors, Gregor Zöttl, and seminar participants at BECCLE Conference, ETH Zurich, Goethe University Frankfurt, Technical University of Berlin, HEC Paris and University Paris Panthéon-Assas (CRED), German Institute for Economic Research (DIW Berlin), University of Nuremberg, Helsinki Graduate School of Economics, Stockholm IFN-workshop. We also thank Mustafa Ispa for his excellent research support.

1 Introduction

Many firms operate in high-risk industries where incidents can have catastrophic consequences for society, including mining, healthcare, pharmaceuticals, airlines, chemical manufacturing, oil and gas drilling, and nuclear energy. These industries are characterized by low-probability but high-impact risks that make traditional approaches to safety management—such as simply making firms liable for damages they cause—largely ineffective. Consequently, policymakers worldwide have implemented comprehensive regulatory frameworks with strict monitoring systems to ensure firms adhere to safety standards.

While empirical evidence demonstrates that increased monitoring improves regulatory compliance across diverse settings (Duflo et al., 2018; Zou, 2021; Muehlenbachs et al., 2019), safety violations persist even across firms in highly regulated industries, where all firms face the same regulatory standards and inspection protocols (Golbe, 1986; Barnett and Higgins, 1989; Kc and Terwiesch, 2009; Kuntz et al., 2015). This heterogeneity in safety outcomes, which cannot be explained by differences in formal regulations, suggests that the quality of regulatory monitoring may vary systematically across facilities. Yet what drives these variations in monitoring quality remains poorly understood.

In this paper, we uncover a previously unrecognized mechanism that creates systematic disparities in regulatory monitoring: the spatial sorting of inspectors by experience level. Using comprehensive data on 105 US nuclear reactors from 2001 to 2020, we find that less experienced inspectors are predominantly assigned to nuclear plants located farther from regional regulatory offices. This pattern appears driven by regional offices being located in major metropolitan areas that may offer better career opportunities and quality-of-life amenities, making nearby assignments more attractive to senior inspectors who have greater influence over their postings.

The nuclear industry provides an ideal empirical setting to study this issue. All facilities

operate under uniform federal regulations administered by the Nuclear Regulatory Commission (NRC), follow standardized safety protocols, and maintain detailed public records due to high-stakes safety requirements. Crucially, the NRC’s resident inspector program—where inspectors are assigned to live near specific facilities for multi-year periods—creates observable variation in inspector assignments while providing unprecedented data on inspector characteristics and their geographic distribution.

We validate that this spatial sorting mechanism has meaningful economic consequences for safety outcomes. Plants assigned less experienced inspectors exhibit significantly worse emergency training performance and higher incident rates. Using quarterly emergency training scores and safety incident frequencies as key measures, we find that the economic magnitude is substantial, as safety incidents are associated with production losses averaging 16 percentage points in capacity utilization and revenue decreases of approximately \$13 million per incident.

Our identification strategy leverages the unique features of the resident inspector program to address key endogeneity concerns. These inspectors conduct daily oversight activities including reviewing operator logbooks, observing plant operations, monitoring equipment tests, and ensuring compliance with safety protocols. Because assignments typically last several years and we can observe inspector experience levels, we exploit within-reactor variation in inspector assignments while controlling for plant characteristics including age, technology type, ownership structure, and market conditions. This approach allows us to isolate the effect of inspector experience from potential confounding factors such as plants with poor compliance histories receiving more intensive monitoring.

Our findings suggest that this relationship operates through differences in inspector effectiveness. While formal regulations are identical across plants, more experienced inspectors are likely to bring deeper regulatory knowledge, better understanding of plant operations, and stronger relationships with facility personnel, advantages that may enhance their ability

to detect safety deficiencies and guide effective remediation.

We further validate our findings through complementary geographic analysis. Facilities located farther from regional regulatory offices show both worse training outcomes and higher incident frequencies, a pattern consistent with the spatial sorting of less experienced inspectors to remote locations. This geographic evidence confirms that administrative decisions about inspector assignments, rather than unobserved plant characteristics, drive the observed safety disparities. Our findings reveal that arguably neutral administrative practices within regulatory agencies can undermine regulatory effectiveness. While formal regulations are identical across plants, the geographic distribution of inspector experience creates systematic variations in monitoring quality.

Our findings make several contribution to the literature. First, we identify a novel source of variation in regulatory effectiveness that operates through internal organizational dynamics rather than external pressures. Unlike previous research focusing on regulatory design and audit effectiveness (Dufflo et al., 2013, 2018; Muehlenbachs et al., 2019), we show that routine administrative decisions about personnel assignments create meaningful disparities in oversight quality.

Second, we provide the first systematic evidence of how geographic factors influence regulatory monitoring in safety-critical industries. While prior work has examined distance effects in monitoring and governance (Kedia and Rajgopal, 2011; Beck et al., 2019; Charoenwong and Umar, 2019), we demonstrate that similar mechanisms operate in safety regulation with potentially catastrophic consequences.

Third, we expand understanding of nuclear safety management (Hausman, 2014; Feinstein, 1989) by shifting focus from market incentives and technological factors to the human capital dimension of regulatory oversight. Our results suggest that inspector characteristics may be as important as institutional design in determining regulatory outcomes.

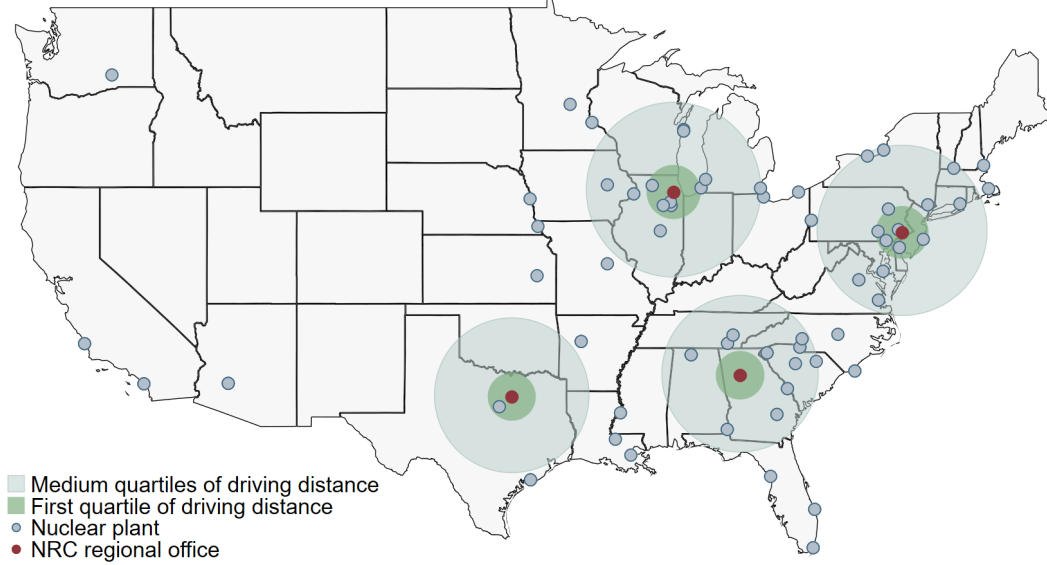
Finally, our findings have policy implications for regulatory design across high-risk in-

dustries. Regulatory agencies should recognize that decentralized oversight structures, while facilitating local monitoring, can introduce systematic biases through inspector sorting. Potential remedies include rotation policies, experience-based assignment quotas for remote facilities, or compensation differentials to attract senior inspectors to less desirable locations. More broadly, our results highlight the importance of considering internal organizational factors when designing regulatory systems intended to provide uniform oversight.

2 Regulatory context and data

Regulatory oversight of the U.S. nuclear industry operates through a multi-layered, decentralized system managed by the Nuclear Regulatory Commission (NRC), an independent agency created by the US Congress in 1974 “to ensure the safe use of radioactive materials for beneficial civilian purposes while protecting people and the environment”. The NRC operates through four regional NRC offices, each responsible for a different geographical area within the US: the Northeast (located in King of Prussia, PA), Southeast (located in Atlanta, GA), Northern Midwest (located in Lisle, IL), and Southern Midwest and West (located in Arlington, TX). To capture geographical variations in oversight, we geo-code each reactor’s location and compute travel time (in minutes) and driving distance (in miles) from the reactor to its respective regional NRC office using Google Maps. Figure 1 displays all 105 commercially operating reactors (blue dots) and the four regional NRC offices (red dots) in our 2001-2020 sample. The circles surrounding each office illustrate the distribution of travel distances: the smaller circles show the first quartile (0 to 125 miles), the larger circles encompass the middle two quartiles (125 to 404 miles), while reactors outside these circles fall in the fourth quartile (404 to 1,890 miles).

Figure 1: NRC offices and nuclear plants in the US. Blue dots show nuclear plants, red dots show the location of regional NRC offices. Circles surrounding the NRC offices display the first quartile (smaller circle) and the two middle quartiles of the distribution of travel distances (larger circle).



2.1 Safety incident data

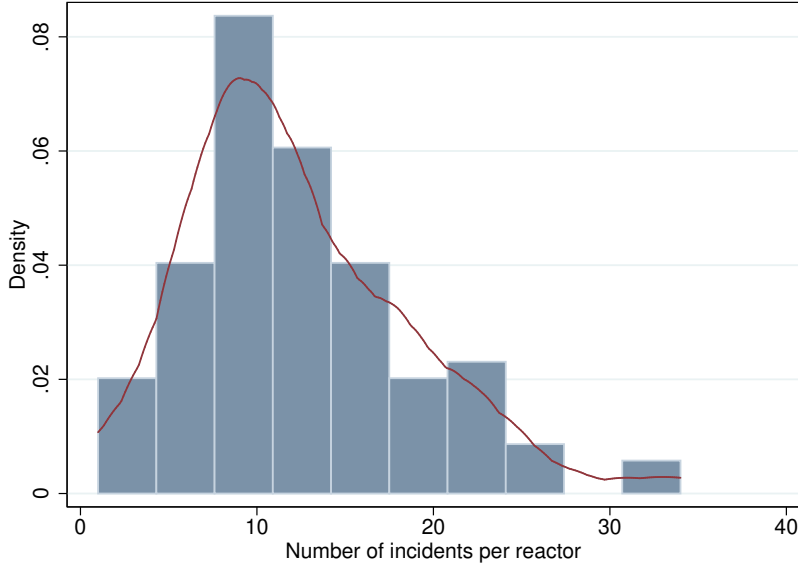
Our main source of data is provided by the NRC, which publishes information for each commercially operating nuclear reactor in the US. We first collect data on safety incidents, known in the industry as *initiating events*, i.e., situations where technical failure or human error has led to unanticipated reactor trips (interruptions in the nuclear chain reaction), resulting in unwanted power outages during commercial operation.¹ These events constitute safety violations that must be reported to the NRC.

We collect all such events for the entire US nuclear power industry from the beginning of 2001 to the end of 2020, obtaining data on 1,309 initiating events, each including a brief textual description. Figure A.1 in the Appendix shows a typical report of an initiating event. Our sample consists of 105 reactors located at 66 sites. Figure 2 illustrates the empirical distribution of reported safety incidents per reactor, revealing considerable variation in the

¹An initiating event is different from a nuclear accident (e.g., core damage) but represents a plant upset that challenges safety functions and may initiate an accident sequence.

number of incidents per reactor, ranging from 1 to 34.

Figure 2: Distribution of safety incidents. Empirical distribution (blue bars) and density estimate (red line) of reported safety incidents for 105 commercially operating nuclear reactors in the US between 2001 and 2020.



2.2 Inspector assignment data

Each regional office assigns resident inspectors to every nuclear power plant within its jurisdiction. These inspectors are stationed near the plants they oversee, often living in nearby communities for the duration of their assignment. Their role involves conducting ongoing, on-site monitoring through periodic regulatory audits and inspections, ensuring consistent safety standards across all nuclear facilities. Beyond routine monitoring, resident inspectors play a crucial role in shaping safety performance by notifying plant management about misconduct or violations of regulatory protocols and implementing corrective actions to improve safety processes ([Nuclear Regulatory Commission, 2022](#)).

We compile comprehensive data on NRC resident inspector assignments using a web crawler program to extract information from the NRC’s official web announcements. Fol-

lowing each new assignment, the NRC publishes an announcement that includes the plant’s name, the new resident inspector’s name, their NRC joining date, and educational background.² This procedure yields data on 417 resident inspectors across our sample period.

For our analysis, we measure inspector experience in terms of years of service at the NRC, which range from zero to 32 years. This inspector-specific measure serves as a proxy for oversight quality at each plant site. Experience and on-the-job learning are crucial for NRC inspectors given the highly specialized nature of their work—each inspector undergoes comprehensive training before their first assignment, with ongoing additional training requirements throughout their career.

2.3 Emergency training data

A key mechanism through which resident inspectors influence plant safety is their oversight of personnel emergency preparedness. We examine this relationship using data on the safety performance of nuclear reactor personnel during standardized emergency exercises.

We leverage the NRC’s systematic collection of granular, time-variant data on personnel training for each US nuclear plant. Specifically, we utilize scores from NRC periodic test drills administered to operating personnel. The NRC conducts these test drills quarterly to assess and score the safety performance of each nuclear reactor’s staff. These exercises simulate emergency scenarios and evaluate personnel response capabilities under the supervision of NRC headquarters and local staff, including the resident inspector assigned to each plant.

The awarded scores range from 0 to 100, although scores below 90 are rare, effectively creating a 10-point scale between 90 and 100. We use these scores as our measure of employee emergency training performance. The data are publicly available from the NRC’s website as part of its oversight policy (data series EP01). Together with our nuclear safety incident

²The NRC states that resident inspectors may not remain at a plant for more than seven years, and they are discouraged from participating in social activities with plant employees. Any previous relationships with plant personnel or contractors must be disclosed.

data, these employee emergency training scores constitute our comprehensive measures of firms’ safety compliance.

2.4 Reactor characteristics data

To ensure our analysis accounts for plant-level heterogeneity that may influence both inspector oversight and safety outcomes, we collect additional data on reactor characteristics and market conditions. Market incentives and plant ownership measures have been shown to affect safety in the nuclear industry (see [Davis and Wolfram \(2012\)](#) and [Hausman \(2014\)](#)), so we use this information to construct a set of control variables. From the US Energy Information Administration (EIA), we collect monthly data on output and revenues at the reactor level.³ Finally, we obtain data on additional reactor characteristics such as age and ownership. The ownership data allows us to isolate price-regulated reactors from commercial ones owned by independent power producers. The ownership data further distinguishes between the operator and the owner, allowing us to assess whether the separation of control from ownership might undermine incentives for safety investments. We therefore refer to reactors as having a ‘separate operator’ if the majority owner is different from the operator of the reactor.⁴

2.5 Summary statistics

Table 1 summarizes the data described above. Panel A shows the summary statistics for the 105 nuclear reactors located at 66 plant sites. Using the year a reactor went online, we construct the age for each reactor. On average, reactors in our sample began operating in 1980, and their average age is 30 years. Regarding technology, 70 of the 105 reactors in our sample are pressurized water reactors (PWR), while the remaining 35 are boiling water reactors

³We calculate reactor revenue by multiplying reactor output by the corresponding monthly state-level retail electricity price, as published by the EIA.

⁴The EIA collects these data in EIA Data Forms 860, 861, and 923.

Table 1: Summary statistics.

	Mean	St. Dev.	Min	Max	Obs
<i>A. Reactor characteristics</i>					
First year of operation	1980	7	1969	2016	105
Travel time [minutes]	317.56	305.70	24	1,680	105
Driving distance [miles]	344.73	353.60	20	1,890	105
Reactor size [MW]	1034.09	227.96	502.00	1,499.40	2,026
<i>B. Inspector experience, reactor personnel, and emergency training</i>					
Experience [years]	6.82	5.56	0	32	412
Personnel [#]	1209.85	660.62	0	3,978	2,033
Emergency training [score]	96.93	1.86	88.70	100	7,513
<i>C. Operational and ownership characteristics</i>					
Average output [0-100]	89.58	24.03	0	100	24,374
Generation [GWh]	650.23	227.76	-25.63	1,077.67	24,374
Revenue [million USD]	62.15	28.25	-3.08	180.24	24,374
Divested [Yes=1]	0.43	0.50	0	1	24,374
Separate operator [Yes=1]	0.14	0.35	0	1	24,374

Panel A shows the age, size and distance to the relevant regulatory office for all nuclear reactors operating in the industry from 2001 to 2020. Statistics for the first year of operation are reported in full years. Observations on reactor size are annual and measured in MW nameplate capacity. Panel B shows the experience of resident inspectors at the time of their assignment to a new plant, the number of staff per plant and the quarterly results of regulatory emergency drills. Panel C shows monthly reactor characteristics from 2001 to 2020, i.e., monthly average output (between 0 for no operation and 100 for operation at full capacity), monthly (net) generation, revenue (calculated as monthly output multiplied by the respective monthly state-level retail price), whether a reactor is regulated or has been divested to a commercial producer in a given month, whether the reactor is operated by a company other than the majority owner.

(BWR). Panel A also presents location data for all 105 reactors and shows the respective distance to their corresponding regional NRC office. As shown earlier in Figure 1, the NRC conducts its activities through four regional offices. The average travel time to a reactor from its respective regional office is 317 minutes, and the average driving distance is 344 miles. Finally, Panel A provides statistics on the size of the reactors, measured in megawatt (MW) nameplate capacity. Here, annual data yield around two thousand observations for

the 105 reactors. As shown, reactor size can vary, occasionally even within the same reactor due to capacity upgrades.

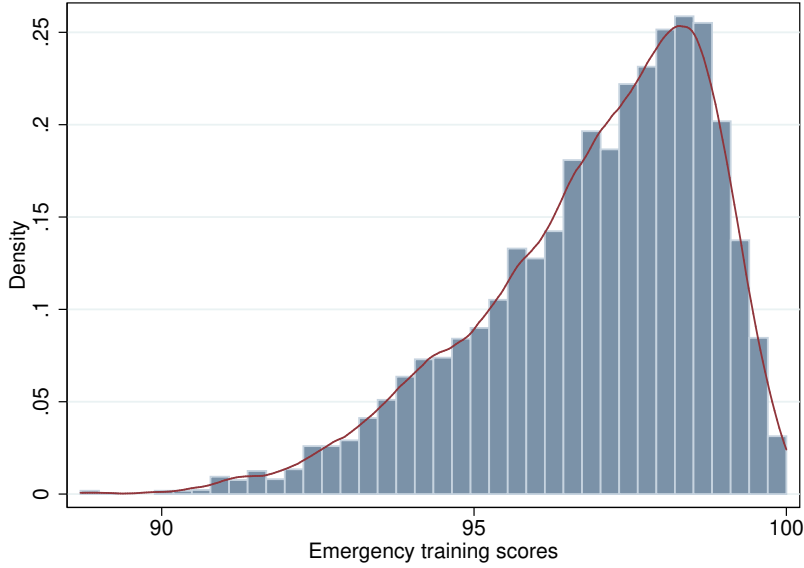
Panel B of Table 1 shows the summary statistics on NRC’s resident inspectors and reactor personnel. As shown, the average experience of inspectors at the time of their assignment to a particular plant (measured in years of service with the NRC) is about seven years. Some inspectors are assigned in their first year with the NRC and have no work experience, while others have up to 32 years of work experience at the time they are assigned to a new plant. The data on the number of personnel working at each plant are annual. As shown, the number of personnel can vary considerably, both within a given plant and over time. It is important to highlight that the personnel figures are for the technical staff operating at the heart of the plant. Indeed, NRC publishes this data as the total “personnel with a measurable dose of radiation”.⁵ Finally, Panel B presents summary statistics on the test scores assigned by the NRC. The data are available every quarter and for each reactor, resulting in about seven thousand observations. Reactors have an average score of almost 97 out of 100, although the score varies considerably between a minimum of about 88 and a maximum of 100. Figure 3 plots the histogram and a density estimate of the emergency training score, displaying significant variation across the sample.⁶

Panel C presents further economic data for each nuclear reactor. It includes the average power (measured on a scale from 0 for no operation to 100 for full capacity operation), monthly (net) electricity generation measured in gigawatthours (GWh), revenue (calculated by multiplying generation with the state-level electricity price), and two variables that pertain to reactor governance and ownership during a specific month. Specifically, the data indicate whether a reactor is still operated by a regulated firm or has been divested to an

⁵For the reactor Fermi 2, the number of reactor personnel is reported to be zero in 2020. Our results holds when excluding the 2020 data for Fermi 2.

⁶In unreported analyses, we also find that the score also varies between different reactors operated by the same owner.

Figure 3: Distribution of emergency training scores. Empirical distribution (blue bars) and density estimate (red line) for the emergency training scores of reactor personnel.



independent commercially operating power company. Further, by comparing annual information on the owner of the reactor to the monthly information of the reactor operator, we can identify reactors where the operator and owner differ.⁷ This variable allows to control for whether there exists a separate operator at the reactor-month level. Arguably, when there is no distinct operator for a reactor, there are more aligned incentives for maintaining safe operation. This monthly reactor panel comprises approximately 24,000 reactor-months observations for the 105 reactors in our sample from 2001 to 2020. Notice that our sample is unbalanced in that 11 reactors exited the market while two reactors went online during the sample period.

2.6 Preliminary evidence on safety-performance relationships

Before proceeding to our main analysis, we provide preliminary evidence on the economic relevance of safety incidents and their relationship with emergency training performance.

⁷In the case of multiple owners, we only consider the majority owner to construct this variable.

This analysis serves to motivate our subsequent examination of how inspector characteristics affect these outcomes and validates that our safety measures capture economically meaningful variation.

We first establish that safety incidents impose substantial economic costs on nuclear plants using our monthly reactor panel. Table 2 presents results from regressions of the form $Y_{it} = \beta_0 + \beta_1 X_{it} + \gamma_t + v_i + \epsilon_{it}$, where Y_{it} represents various outcome measures for reactor i in month t , and X_{it} is our key explanatory variable. All specifications include month-year fixed effects (γ_t) and reactor fixed effects (v_i), with standard errors clustered at the reactor level.⁸

Table 2: Safety and operating performance.

	(1) Output	(2) Revenue	(3) Incidents	(4) Output	(5) Revenue
Incidents	-16.021*** (0.781)	-13.133*** (0.745)			
Emergency training			-0.091*** (0.017)	0.427*** (0.160)	3.172*** (0.228)
Month x year fixed effects	Yes	Yes	Yes	Yes	Yes
Reactor fixed effects	Yes	Yes	Yes	Yes	Yes
R ²	0.11	0.51	-	0.08	0.56
Observations	24,374	24,374	22,536	22,536	22,536

Reactor-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Column (1) examines the impact of safety incidents on reactor output, measured as capacity utilization (0-100 scale). The results show that one additional incident is associated with a 16 percentage point decrease in average reactor utilization in the corresponding month. Column (2) uses total monthly revenue as the dependent variable, revealing that each additional incident corresponds to an average revenue drop of approximately USD 13 million.

⁸Results are robust to additional control variables and plant-level clustering.

Having established the economic significance of safety incidents, we next examine their relationship with emergency training performance. Column (3) uses a negative binomial regression with the number of incidents as the dependent variable and emergency training scores as the key explanatory variable. We find a negative and statistically significant relationship: a unit increase in emergency training (approximately half a standard deviation) is associated with a 9% lower probability of incidents.⁹

Columns (4) and (5) complete the causal chain by demonstrating that better emergency training translates into improved economic performance through reduced incidents. Higher emergency training scores are associated with increased output and revenue, as fewer incidents mean fewer production shutdowns.¹⁰

This preliminary analysis establishes two key facts that motivate our main investigation: safety incidents impose substantial economic costs on nuclear facilities, yet significant disparities in safety performance persist across plants. These findings validate our focus on understanding how regulatory oversight influence these economically important safety outcomes.

3 Regulatory oversight and safety compliance

This section examines whether the observed variation in nuclear plants’ safety performance can be attributed to differences in regulatory oversight. Although nuclear regulation is formulated at the national level and compliance monitoring is implemented through a standardized and uniformly structured framework across facilities, an important source of variation lies

⁹The percentage change in expected incident count is calculated as $(e^{-0.091} - 1) \times 100 = -8.6\%$. Note that emergency training data are unavailable for reactors that exited during our observation period, reducing the sample size for Columns (3)-(5).

¹⁰Additional analysis parsing textual descriptions from NRC event reports using keyword identification (see [Gentzkow et al. \(2019\)](#)) distinguishes between human-factor and technical-failure incidents. We find that emergency training significantly reduces both types, with particularly strong effects on human-related safety incidents.

in the assignment of resident inspectors. We focus on understanding how inspectors are matched to specific plants and argue that this matching process is not random. By analyzing the criteria behind these assignments, we show that they provide a plausible explanation for the variation in safety outcomes across plants.

3.1 The inspector-plant matching

Each nuclear facility is monitored by two resident inspectors stationed on-site.¹¹ These inspectors spend a substantial amount of time observing daily operations and reporting to the Nuclear Regulatory Commission (NRC). They are assigned to plants by one of the NRC’s four regional offices. In this subsection, we investigate whether the assignment of inspectors is driven by one or multiple underlying sorting mechanisms. Specifically, we examine whether the characteristics of nuclear plants are systematically associated with the attributes of the inspectors to whom they are assigned. To conduct this analysis, we use the information from public announcements released by the Nuclear Regulatory Commission (NRC) each time a new resident inspector is appointed to a plant. These announcements provide a range of inspector attributes, including the year the inspector joined the NRC, whether they hold a master’s degree, and whether they receive a senior title. The latter is typically awarded to inspectors with extended tenure at the NRC or those possessing equivalent relevant experience. Crucially, the reported year of entry into the NRC enables us to construct a measure of work experience, defined as the number of years employed at the NRC, for all resident inspectors assigned between 2001 and 2020. In total, our dataset comprises information on 412 inspector assignments.¹²

To analyze the matching of inspectors to plants, we estimate a series of regression models. Let Y_{ijt} denote a specific characteristic of plant i paired with inspector j at time t , depend-

¹¹Larger plants, e.g., with three reactor units, typically have three inspectors.

¹²Five inspector assignments were excluded from the analysis due to missing information on work experience.

ing on the sorting dimension being examined. The set of explanatory variables includes all observable attributes of inspector j , specifically their tenure at the NRC, educational qualifications, and senior title. Formally, we estimate

$$Y_{ijt} = \beta_0 + \beta_1 Experience_{ijt} + \beta_2 Master\ degree_{ijt} + \beta_3 Senior\ title_{ijt} + \gamma_t + \epsilon_{ijt}, \quad (1)$$

where $Experience_{ijt}$ is the logarithm of work experience of inspector j paired with plant i at time t , $Master\ degree_{ijt}$ is a dummy variable set to one if the inspector has a master's degree at the time of their new assignment, and $Senior\ title_{ijt}$ is a dummy set to one if the inspector is a higher-paid inspector. We include sample month fixed effects, γ_t . Thus, each regression tests for a different sorting mechanism of inspectors to plants. Since inspectors are assigned to plant sites (rather than to each individual reactor), we cluster standard errors at the plant level.¹³

Table 3 summarizes the results on whether inspector characteristics are systematically associated with plant attributes at the time of assignment. Column (1) reports the results using the age of plant i at the time inspector j is assigned (i.e., at time t) as the dependent variable. Prior work by Bizet et al. (2022) has shown that plants of different ages exhibit distinct safety performance patterns.¹⁴ This observation suggests that inspector assignments may be systematically related to plant age, for instance, if more experienced or highly educated inspectors are allocated to older or newer facilities. However, the estimates in Column (1) provide no statistically significant evidence of such sorting based on inspector characteristics.

¹³To avoid losing observations on inspectors in their first year, i.e., with zero work experience, we use $\log(Experience_{ijt} + 1)$. Our results hold if we exclude those inspectors.

¹⁴Joskow and Rozanski (1979) also documents that nuclear power plants constructed in different years display variation in capacity factors.

Table 3: Sorting of inspectors to nuclear plants.

	Plant type		Size and operational			Safety		Geography	
	Age	Technology	Size	Plant Personnel	Output	Emergency training	Past incidents	Population	Miles to regulator
	<i>OLS</i>	<i>Logit</i>	<i>OLS</i>	<i>OLS</i>	<i>OLS</i>	<i>OLS</i>	<i>Neg. bin.</i>	<i>OLS</i>	<i>OLS</i>
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Experience	-0.826 (0.913)	0.118 (0.204)	11.603 (32.491)	0.011 (0.089)	0.905 (2.817)	0.001 (0.002)	-0.005 (0.046)	0.251* (0.127)	-0.262** (0.124)
Master degree	-0.467 (0.734)	-0.081 (0.196)	17.264 (27.022)	-0.141 (0.099)	2.274 (3.175)	-0.004 (0.002)	0.077 (0.051)	-0.033 (0.122)	0.098 (0.099)
Senior title	0.609 (1.046)	-0.166 (0.242)	11.152 (41.823)	-0.105 (0.118)	-0.673 (3.292)	-0.002 (0.003)	-0.082 (0.058)	-0.264 (0.186)	0.368** (0.183)
Month x year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R ²	0.68	-	0.41	0.41	0.49	0.62	-	0.50	0.47
Observations	412	412	412	412	412	361	412	412	412

Plant-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Columns (2) through (9) of Table 3 examine a range of alternative sorting mechanisms. Column (2) presents the results from a logit regression, where the dependent variable equals one for pressurized water reactors and zero for boiling water reactors. The results indicate no statistically significant link between inspector characteristics—such as experience, education level, or senior title—and the assignment to different reactor technologies.

Columns (3) to (5) investigate whether inspector types are systematically matched to plants with specific operational characteristics. We consider plant size (measured by nameplate capacity), the number of plant personnel (log-transformed), and plant output (expressed as a percentage of full capacity, where zero indicates no output and 100 denotes full-capacity operation). Across these specifications, we find no significant evidence of sorting based on operational features.

Columns (6) and (7) explore whether assignment patterns are related to plant safety characteristics. Column (6) uses the logarithm of the plant’s emergency training score as the dependent variable, while Column (7) estimates a negative binomial regression with the plant’s cumulative incident count—measured up to the time of the inspector’s assignment as the outcome. In both cases, the results show no statistically significant matching pattern, i.e., more experienced inspectors are not systematically matched with plants with worse trained emergency staff or with plants with higher past incident rates.

Finally, Columns (8) and (9) examine the potential for spatial sorting in inspector assignments. In Column (8), we test whether more experienced inspectors are systematically assigned to plants located in more densely populated areas, as measured as the logarithm of the surrounding population. Such facilities may be considered more sensitive due to higher potential public exposure. Alternatively, the assignment pattern may reflect supply-side factors, such as the availability of a larger local labor market or the ability of experienced inspectors to exercise greater bargaining power in securing positions in urban rather than rural or remote locations. The results indicate that inspectors with greater work experience

are more likely to be assigned to plants with higher surrounding population, although the coefficient is statistically significant only at the 10% level.

Column (9) investigates whether assignment patterns are influenced by proximity to the NRC’s regional offices, using the logarithm of the distance (in miles) from the plant to the corresponding regional office as the dependent variable. The results reveal that more experienced inspectors are systematically assigned to plants located closer to regional offices. This sorting pattern may reflect preferences for locations that offer enhanced professional networking opportunities, both within the NRC and with external institutions, in addition to better amenities and stronger local labor markets that are typically found near regional office locations. Moreover, this relationship is estimated with greater precision than the effect reported in Column (8). In magnitude, a doubling of inspector experience is associated with an approximate 26 percent reduction in travel distance.¹⁵

In unreported analysis, we find that the previously observed association between inspector experience and assignment to plants in more densely populated areas (as shown in Column (8) of Table 3) becomes statistically insignificant once we control for the distance between the plant and the NRC’s regional office. In contrast, the negative relationship between inspector experience and distance to the regional office (reported in Column (9)) remains statistically significant even after accounting for the surrounding population. This pattern suggests that the sorting of more experienced inspectors is driven by proximity to the regulatory office itself rather than to urban areas more generally.

Table 4 presents a series of robustness checks that further substantiate the hypothesis of inspector–plant sorting. Column (1) demonstrates that the estimated relationship remains statistically significant after the inclusion of fixed effects for the four NRC regional jurisdictions and after controlling for each plant’s distance to the nearest major city. Columns (2)

¹⁵To put the estimate in perspective, an inspector with approximately three years of experience (at the 25th percentile of the experience distribution) is, on average, assigned to a plant roughly 200 miles farther from the regional office than an inspector with around ten years of experience (at the 75th percentile).

Table 4: Sorting of junior and senior inspectors.

	Miles to regulator			Travel time to regulator		
	(1)	(2)	(3)	(4)	(5)	(6)
Experience	-0.176** (0.075)	-0.354** (0.150)	-0.287 (0.258)	-0.155** (0.069)	-0.312** (0.136)	-0.259 (0.241)
Master degree	0.092 (0.086)	0.164 (0.186)	-0.015 (0.195)	0.085 (0.081)	0.150 (0.168)	-0.009 (0.179)
Senior title	0.194* (0.112)			0.178* (0.105)		
Population	-0.098 (0.140)			-0.083 (0.130)		
Distance large city	0.111 (0.216)			0.109 (0.202)		
Month x year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	No	No	Yes	No	No
R ²	0.69	0.68	0.69	0.59	0.70	0.59
Observations	412	235	177	412	235	177

Plant-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

and (3) reproduce the specification separately for junior and senior inspectors, respectively; the estimated effect is evident only for the former group, indicating that the spatial allocation mechanism operates predominantly among less-experienced inspectors. Collectively, these findings confirm that the observed sorting cannot be attributed merely to urban proximity but instead reflects a systematic preference for locations situated closer to the regulatory office. Finally, the results are robust to redefining proximity in terms of travel time (minutes) rather than travel distance (miles), as shown in Columns (4) to (6).

3.2 Inspector experience and safety compliance

To evaluate the practical consequences of the inspector-plant matching documented above, we investigate whether the level of inspector experience is associated with differences in reactor safety outcomes. Specifically, we use data collected by the regulator on emergency preparedness, measured through the performance of reactor personnel during formally administered on-site emergency training exercises.

In our baseline specification, we estimate the following equation:

$$Emergency\ training_{it} = \beta_0 + \beta_1 Experience_{ijt} + X_{ijt}\beta + v_i + \gamma_t + \epsilon_{ijt}, \quad (2)$$

where $Emergency\ training_{it}$ is the logarithm of the training score awarded to reactor i in quarter t . Our main explanatory variable is $Experience_{ijt}$, which measures the work experience of the last inspector to arrive at plant i . To take full advantage of the longitudinal data on reactor emergency training scores, we construct this as a running experience variable that increases by one unit for each subsequent year after that inspector’s arrival. In other words, $Experience_{ijt}$ captures the continuously increasing work experience (in logs) of the last inspector assigned to each nuclear power plant.

We also include a set of control variables, denoted by the matrix X_{ijt} , quarterly fixed effects γ_t , and, depending on the specification, reactor fixed effects v_i . Standard errors are clustered at the reactor level to account for potential serial correlation, as repeated observations over time may be correlated within the same reactor—for instance, if poor training performance influences subsequent preparedness efforts. As a robustness check, we also cluster at the plant level to address possible cross-reactor correlation, given that a single inspector typically oversees all reactors within the same plant site.

Table 5 displays the regression results, showing that higher experience of inspectors is positively associated with better emergency training for reactor personnel. Notice that this

finding is robust to estimating a simple regression in Column (1) of Table 5, and adding as control variables the reactor’s characteristics used earlier, that is its age and technology in Column (2), its operational characteristics size, personnel, and output in Column (3), relevant safety characteristics, i.e., its (running) incident count as well as, in Column (4), its spatial characteristics in terms of population in the nearby area and distance to regional regulator’s office. Controlling for the latter makes sure that we isolate the effect of inspectors’ experience, which (as we have shown) is correlated with distance to the regulator’s regional offices. In Column (5), we furthermore control for whether a reactor is divested or not. In line with the findings in [Hausman \(2014\)](#) that divested reactors have fewer safety incidents, the point estimate suggests that divested reactors also have better-trained staff. Yet, the coefficient of inspectors’ experience remains significant to the inclusion of this control. Finally, in Column (6) we show that our estimates are likewise robust to including reactor fixed effects (and removing the controls for reactors’ technology, surrounding population, and miles to the regulator, which are time-invariant).

In terms of magnitude, the estimate in our richest specification in Column (5) suggests that a doubling of inspector experience increases a reactor’s emergency training score by 0.3 percent. Evaluated at the mean emergency training score of 97, this is an increase of about 0.3, or about one-sixth of a standard deviation. To monetize this improvement in emergency training, recall our estimates in Table 2 on the impact of emergency training on reactors’ economic outcomes. Applying the above 0.3 improvement in emergency training scores yields an average increase in monthly revenue of about USD 1 million per reactor per month, or an increase in revenue of about USD 1.2 billion per year at the industry level.¹⁶

In Table A.1 in the Appendix, we also show that our estimates are robust to using standard errors clustered at the plant level and using plant level fixed effects, and when

¹⁶We approximate industry gains as USD 1 million revenue per reactor times 100 reactors and twelve months.

controlling for whether a reactor is operated by another firm as the owner.

Table 5: Inspector experience and emergency training.

	Emergency training					
	(1)	(2)	(3)	(4)	(5)	(6)
Experience	0.002*** (0.001)	0.003*** (0.001)	0.003*** (0.001)	0.002*** (0.001)	0.003*** (0.001)	0.002** (0.001)
Age		-0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
Technology		-0.005*** (0.001)	-0.004*** (0.002)	-0.005*** (0.002)	-0.004*** (0.002)	
Size			0.006** (0.003)	0.006* (0.003)	0.006* (0.003)	-0.022** (0.011)
Personnel			0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)
Output			0.033* (0.017)	0.027 (0.017)	0.026 (0.017)	0.010 (0.013)
Incidents				0.000 (0.001)	0.000 (0.001)	0.000 (0.000)
Population				0.001 (0.001)	0.001 (0.001)	
Miles to regulator				-0.001 (0.001)	-0.001 (0.001)	
Divested					0.001 (0.002)	0.009** (0.005)
Quarter x year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Reactor fixed effects	No	No	No	No	No	Yes
R ²	0.37	0.39	0.39	0.40	0.40	0.51
Observations	6,049	6,049	6,030	6,030	6,030	6,030

Reactor-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Our findings broadly suggest that inspectors differ in their monitoring ability (which increases as a function of on-the-job experience). To the extent that less experienced inspectors possess less extensive knowledge of regulatory protocols and/or plant characteristics, assigning such inspectors to plants located far away from the regulatory office explains the below-par emergency training. In fact, safety may decline either because less experienced inspectors do not identify and improve all possible deficiencies in the daily operation of the plant and/or because plant management adjusts downwards its decision to invest in safety training in anticipation of such less stringent monitoring. While we cannot disentangle these two effects, our results demonstrate significant variation in monitoring outcomes, driven by differences in inspectors' experience

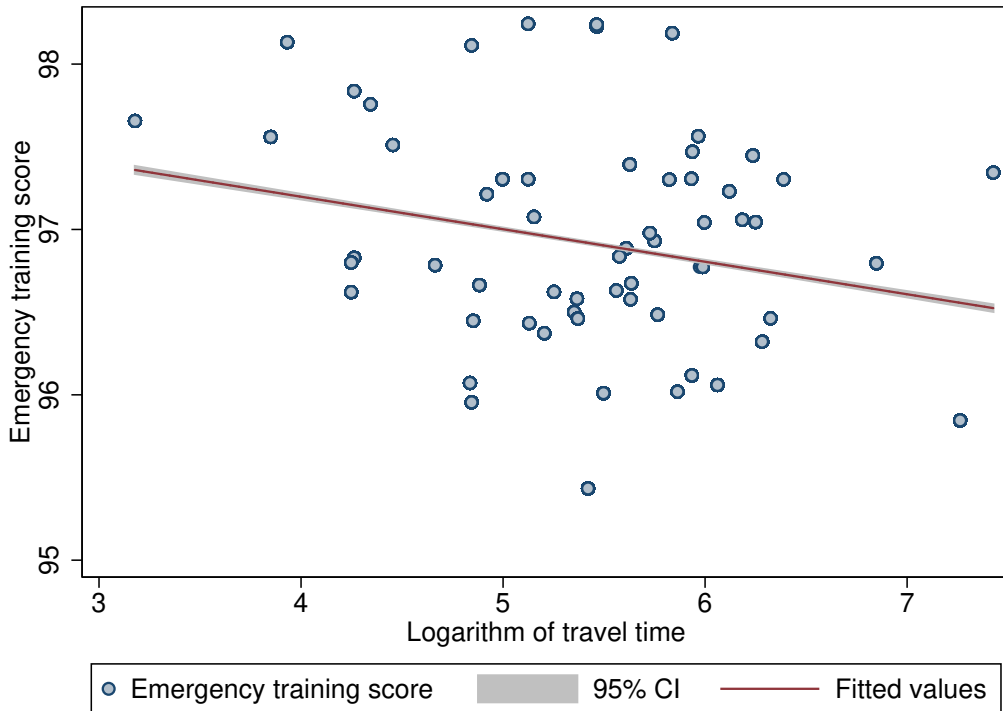
4 Geographic proximity and safety performance

The previous analysis established that less experienced inspectors are systematically assigned to plants farther from regional NRC offices, leading to lower emergency training performance at these facilities. This section examines the broader spatial implications of this sorting mechanism by directly analyzing the relationship between geographic proximity to regulatory offices and safety outcomes across the nuclear industry.

If our proposed mechanism operates as hypothesized, we should observe a clear spatial pattern in safety performance that mirrors the geographic distribution of inspector experience. Specifically, plants located farther from regional offices should exhibit systematically lower emergency training scores and potentially higher incident rates, reflecting the reduced monitoring effectiveness of less experienced inspectors assigned to these remote locations.

Figure 4 plots the relationship between average emergency training scores at each reactor and the logarithm of distance to the corresponding regional NRC office. The data reveal a strong negative association between emergency training performance and distance to the

Figure 4: Emergency training and distance to regulatory office. Blue circles show the average emergency training score of a reactor during our sample period. Distance is measured as the logarithm of driving distance (in miles) from a reactor to its corresponding regional NRC office. The red line plots a linear fit.



regulatory office. This pattern is consistent with our earlier evidence on spatial matching of regulatory inspectors, whereby less experienced inspectors are assigned to plants more remote from regional offices, resulting in declining training performance of reactor personnel.

We also investigated spatial patterns in the frequency of safety incidents. While we find only limited evidence for a linear relationship between plant-regulator proximity and incident frequency, our analysis reveals significant evidence when examining non-linear, discrete spatial patterns. This finding aligns with the notion that travel distances matter not linearly but rather in terms of practical thresholds—such as whether distances allow for same-day round trips or require air travel for remote facilities. Specifically, reactors located in the higher quartiles of travel distance from their regional office exhibit approximately threefold

higher probability of experiencing safety incidents. These results are presented in Table A.2 in the Appendix.

5 Conclusion

Effective safety regulation in high-risk industries depends critically on the quality and consistency of regulatory monitoring. This paper contributes to our understanding of how inspector characteristics and spatial factors influence regulatory effectiveness by examining the universe of nuclear power plants in the US between 2001 and 2020. Our analysis provides novel evidence on a previously unexplored aspect of regulatory design: the systematic sorting of inspectors based on experience and geographic proximity to regulatory offices.

Our analysis reveals substantial variation in safety performance across nuclear plants, as measured by both incident rates and emergency training scores. We demonstrate that this variation is not random but follows a clear spatial pattern linked to inspector assignment mechanisms. Specifically, we find that more experienced inspectors are systematically assigned to plants located closer to regional NRC offices, while less experienced inspectors monitor plants in more remote locations. This spatial sorting has meaningful consequences: plants assigned less experienced inspectors exhibit significantly lower emergency training performance, and remote plants—which predominantly receive less experienced inspectors—experience both inferior training outcomes and higher incident rates.

Our findings have important implications for regulatory design in high-risk industries beyond nuclear power. The systematic assignment of less experienced inspectors to geographically remote facilities may be a widespread phenomenon that affects safety outcomes across multiple regulated sectors. This suggests that regulatory agencies should carefully consider the geographic distribution of inspector experience when designing oversight systems.

From a policy perspective, our results highlight several potential reforms. Regulatory agencies could implement rotation systems that ensure more even distribution of experienced inspectors across geographic regions, provide enhanced training and support for inspectors assigned to remote locations, or develop technological solutions to reduce the monitoring disadvantages associated with distance. More broadly, our findings suggest that seemingly neutral administrative decisions about inspector assignments can have far-reaching consequences for public safety.

The nuclear industry’s unique combination of high stakes, detailed record-keeping, and standardized safety protocols provides an ideal setting for identifying these effects. However, the fundamental mechanisms we document—experience-based performance differences and geographic sorting in regulatory assignments—are likely to operate across many regulated industries where public safety depends on consistent, high-quality monitoring.

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Appendix

Figure A.1: Example of initiating event report.

NRC FORM 366 (01-2014)	U.S. NUCLEAR REGULATORY COMMISSION	APPROVED BY OMB: NO. 3150-0104	EXPIRES: 01/31/2017						
 LICENSEE EVENT REPORT (LER) (See Page 2 for required number of digits/characters for each block)		Estimated burden per response to comply with this mandatory collection request: 80 hours. Reported lessons learned are incorporated into the licensing process and fed back to industry. Send comments regarding burden estimate to the FOIA Privacy and Information Collections Branch (T-5 F53), U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by Internet e-mail to InfoCollections.Resource@nrc.gov, and to the Desk Officer, Office of Information and Regulatory Affairs, NEOB-10202, (3150-0104), Office of Management and Budget, Washington, DC 20503. If a measure used to impose an information collection does not display a currently valid OMB control number, the NRC may not conduct or sponsor, and a person is not required to respond to, the information collection.							
1. FACILITY NAME		2. DOCKET NUMBER	3. PAGE						
Oyster Creek, Unit 1		05000219	1 OF 3						
4. TITLE									
Reactor SCRAM due to Decreasing Reactor Water Level									
5. EVENT DATE		6. LER NUMBER	7. REPORT DATE						
MONTH	DAY	YEAR	YEAR SEQUENTIAL NUMBER REV. NO.						
10	12	2014	2014 - 008 - 01 08 11 2015						
		8. OTHER FACILITIES INVOLVED							
		FACILITY NAME	DOCKET NUMBER						
		N/A	N/A						
		FACILITY NAME	DOCKET NUMBER						
		N/A	N/A						
9. OPERATING MODE									
11. THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: (Check all that apply)									
N	☐ 20.2201(b)		☐ 20.2203(a)(3)(f)	☐ 50.73(a)(2)(i)(C)	☐ 50.73(a)(2)(vii)				
	☐ 20.2201(d)		☐ 20.2203(a)(3)(ll)	☐ 50.73(a)(2)(ii)(A)	☐ 50.73(a)(2)(viii)(A)				
	☐ 20.2203(a)(1)		☐ 20.2203(a)(4)	☐ 50.73(a)(2)(ii)(B)	☐ 50.73(a)(2)(viii)(B)				
	☐ 20.2203(a)(2)(l)		☐ 50.36(c)(1)(i)(A)	☐ 50.73(a)(2)(iii)	☐ 50.73(a)(2)(ix)(A)				
10. POWER LEVEL		☐ 20.2203(a)(2)(ll)	☐ 50.36(c)(1)(ii)(A)	☒ 50.73(a)(2)(iv)(A)	☐ 50.73(a)(2)(x)				
1%	☐ 20.2203(a)(2)(lll)		☐ 50.36(c)(2)	☐ 50.73(a)(2)(v)(A)	☐ 73.71(a)(4)				
	☐ 20.2203(a)(2)(lv)		☐ 50.46(a)(3)(ll)	☐ 50.73(a)(2)(v)(B)	☐ 73.71(a)(5)				
	☐ 20.2203(a)(2)(v)		☐ 50.73(a)(2)(i)(A)	☐ 50.73(a)(2)(v)(C)	☐ OTHER				
	☐ 20.2203(a)(2)(vi)		☐ 50.73(a)(2)(l)(B)	☐ 50.73(a)(2)(v)(D)	Specify in Abstract below or in NRC Form 366A				
12. LICENSEE CONTACT FOR THIS LER									
FACILITY NAME				TELEPHONE NUMBER (Include Area Code)					
Michael McKenna, Regulatory Assurance Manager				(609) 971-4389					
13. COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT									
CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO EPIX	CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO EPIX
A	N/A	N/A	N/A	N	N/A	N/A	N/A	N/A	N/A
14. SUPPLEMENTAL REPORT EXPECTED						15. EXPECTED SUBMISSION DATE			
☐ YES (If yes, complete 15. EXPECTED SUBMISSION DATE) ☒ NO						MONTH	DAY	YEAR	
						03	13	15	
ABSTRACT (Limit to 1400 spaces, i.e., approximately 15 single-spaced typewritten lines)									
On October 12, 2014, an automatic SCRAM occurred during the reactor startup evolution following the 1R25 refueling outage. The SCRAM occurred when a station electrician, in conjunction with a General Electric technician and a site engineer, secured power to the Main Generator Automatic Voltage Regulator (AVR) controllers while the Main Turbine warming evolution was in progress. The individuals were not authorized to perform this action nor did they have procedures in the field to operate the equipment. Their actions resulted in an automatic reactor SCRAM on low water level. ENS 50524 was submitted on October 12, 2014, and updated on October 17, 2014. This issue is reportable under 10 CFR 50.73(a)(2)(iv)(A), because it involved an event or condition that resulted in manual or automatic actuation of any of the systems listed in paragraph (a)(2)(iv)(B). The Root Cause Analysis was completed on January 30, 2015. The cause of this event was determined to be that Station Leadership has inconsistently reinforced Human Performance Error Reduction Tool Use and Procedure Use and Adherence. This resulted in the breakdown of multiple fundamental practices and standards that led to the event.									

Table A.1: Inspector experience and emergency training, robustness tests.

	Emergency training					
	(1)	(2)	(3)	(4)	(5)	(6)
Experience	0.002** (0.001)	0.003** (0.001)	0.003** (0.001)	0.002** (0.001)	0.003** (0.001)	0.002* (0.001)
Age		-0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
Technology		-0.005*** (0.002)	-0.004** (0.002)	-0.005** (0.002)	-0.004** (0.002)	
Size			0.006 (0.004)	0.006 (0.004)	0.005 (0.004)	-0.009 (0.007)
Personnel			0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)
Output			0.033* (0.019)	0.027 (0.018)	0.026 (0.018)	0.010 (0.013)
Incidents				0.000 (0.001)	0.000 (0.001)	0.000 (0.000)
Population				0.001 (0.001)	0.001 (0.001)	
Miles to regulator				-0.001 (0.001)	-0.001 (0.001)	
Divested					0.001 (0.003)	0.009 * (0.006)
Separate owner					0.001 (0.002)	0.004*** (0.001)
Quarter x year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Plant fixed effects	No	No	No	No	No	Yes
R ²	0.37	0.39	0.39	0.40	0.40	0.51
Observations	6,049	6,049	6,030	6,030	6,030	6,030

Plant-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.2: Safety incidents and proximity to the regulator's regional office.

	Incidents (<i>negative binomial regression</i>)			
Miles to regulator	0.069 (0.054)			
Driving time		0.069 (0.058)		
Miles to regulator (2 nd and 3 rd quartile)			0.296** (0.147)	
Miles to regulator (4 th quartile)			0.317* (0.168)	
Driving time (2 nd and 3 rd quartile)				0.311** (0.138)
Driving time (4 th quartile)				0.353** (0.166)
Age	-0.016** (0.008)	-0.016** (0.008)	-0.018** (0.007)	-0.017** (0.007)
Technology	-0.216** (0.106)	-0.213** (0.106)	-0.240** (0.103)	-0.214** (0.101)
Distance large city	-0.063 (0.072)	-0.062 (0.073)	-0.062 (0.072)	-0.050 (0.071)
Population	0.161*** (0.027)	0.159*** (0.026)	0.201*** (0.034)	0.205*** (0.034)
Month x year fixed effects	Yes	Yes	Yes	Yes
Observations	24,374	24,374	24,374	24,374

Reactor-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$