Regulation, Compliance, and Proximity: Evidence from Nuclear Safety*

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Abstract

Effective regulation relies on monitoring the compliance of regulated firms. Using a dataset with unique information on regulatory inspections and employees' emergency training in the universe of US nuclear plants, we study how regulatory monitoring determines compliance with nuclear safety procedures. We find that nuclear plants farther from the regulator's regional office exhibit more incidents, and their employees are less trained to deal with emergencies. These spatial differences exist despite regulatory monitoring is conducted daily through resident inspectors (i.e., continuous, decentralized monitoring). The matching between resident inspectors and nuclear plants helps to explain this puzzle: less experienced inspectors are assigned to more distant nuclear plants, and this assignment leads to a decline in employees' emergency training.

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1 Introduction

In many industries, sustaining safe operations is of great importance for liable firms but also for society at large. Yet, holding firms fully accountable for the societal damages of incidents has proven impractical, if not impossible. Consequently, strict regulation and external monitoring become the main policy lever to bolster safety in firms' operations. This consideration has motivated a long-running literature on the regulation of firms that carry out socially risky activities (Magat and Viscusi, 1990; Hiriart and Martimort, 2012; Duflo et al., 2013, 2018).

Despite a strenuous effort by regulators, existing findings indicate that safety incidents are hard to eradicate. In fact, firms have been shown to exhibit poor compliance and unsafe operations even in industries that are highly regulated and subject to stringent regulatory protocols, such as the airline industry (Golbe, 1986; Barnett and Higgins, 1989) or health-care (Kc and Terwiesch, 2009; Kuntz et al., 2015). This evidence suggests that regulatory monitoring might differ in its ability to bolster safety and deter firms' hazardous behaviors. However, quantifying the effect of regulatory monitoring on firms' safety is challenging due to the endogeneity of regulatory monitoring itself (firms with poor compliance may experience more frequent regulatory audits) and the paucity of data on how inspections are carried out.

The nuclear power industry is an ideal setting to address these issues. Due to the immense risks involved, regulatory bodies impose stringent rules to ensure rigorous standards of safety at all nuclear facilities. Yet, as we will show, even in this context there are significant differences in the likelihood of safety incidents, which occur in a non-random fashion across nuclear plants.[1] We argue that these variations may be driven by how geographic proximity

[1] These differences are also known to the regulatory authority, which "is aware of differences across regional offices in identifying and resolving findings that result from physical inspections", see US Government Accountability Office (2013) for a recent report and Feinstein (1989) for early evidence on the occurrence of nuclear incidents. In a similar vein, Hausman (2014) finds that safety differs between divested and regulated nuclear power plants.

shapes the quality of regulatory monitoring.

Existing works have explored the role of geographic proximity between firms and US regulatory authorities such as the SEC (Kedia and Rajgopal, 2011), the IRS (Kubick et al., 2017) and the DOJ (Ha et al., 2024).[2] The bulk of this evidence suggests that geographic proximity improves firms' compliance by facilitating access to local information on the regulated firms and reducing the monitoring costs faced by the regulator. The US nuclear power industry provides a different case because monitoring in such industry is conducted through periodic regulatory audits and inspections done by resident (also called on-site) inspectors who are assigned by the Nuclear Regulatory Commission (NRC) to live close to each nuclear plant for a given amount of time. The NRC has four regional offices, which assign resident inspectors to monitor the activities of all nuclear reactors scattered across the US territory. These inspectors are nuclear power experts who collect timely information from the reactor's control room and immediately notify the plant management of safety issues that might occur. As such, they can directly influence the safety preparedness of nuclear plants' personnel.

Because resident inspectors are close to nuclear plants by design, the concern that geographic distance hampers the access to local information on the regulated firms is minimal. However, decentralized monitoring in our setting might suffer from two problems. First, resident inspectors tend to live far from the regional NRC office and thus have worse access to centralized knowledge and information from their peers at the regional office. Second, resident inspectors assigned to plants in remote areas may have limited opportunities for social interactions and thus develop social ties with plants' employees, losing objectivity in monitoring. Both of these issues are salient among industry experts and the NRC itself, as shown in US Government Accountability Office (2013) regarding the importance of accessing

[2]In parallel, extant literature has investigated the role of geographic proximity in corporate finance by focusing on the distance between firms and board members (Alam et al., 2014; Ayers et al., 2011), banks (Agarwal and Hauswald, 2010), institutional investors (Chhaochharia et al., 2012), mutual funds (Ellis et al., 2020), and corporate headquarters (Giroud, 2013).

centralized knowledge and information sharing, and Nuclear Regulatory Commission (2022) on the discouragement of social interactions between resident inspectors and plant employees. Due to these competing forces, the net effect of decentralized monitoring on nuclear safety is unclear.

We carry out the empirical analysis by exploiting information on the occurrence and underlying cause of all incidents in the US fleet of 105 nuclear reactors (located at 66 plant sites) from 2001 to 2020. This information on nuclear incidents provides a measure of safety compliance. We complement this information with a new dataset on the level of emergency training of nuclear reactors' employees (as assessed by the NRC during its periodic test drills, which simulate emergencies and provide a score of the employees' response performance). Finally, we gather data on the turnover of resident inspectors at nuclear plants and their career history. Leveraging the richness of this data, we explore: (1) how geographic proximity between a nuclear plant and the regional NRC office influences the likelihood of incidents and the level of employees' emergency training, and (2) how NRC inspectors' spatial assignment, considering their diverse job experience, affects the level of reactor employees' emergency training, i.e. their ability to prevent and handle emergencies at the nuclear plant.

Given their severity, one may expect incidents to occur primarily due to random events outside the firm's control. This is because nuclear plant managers internalize the societal cost of safety slack or because regulation is error-free (i.e., it makes nuclear plants achieve a zero incident rate). Countering this view, we show that incidents, both related to human error and technical hardware failure (identified by parsing the textual description of incidents), do occur: our sample contains 1,309 incidents, of which 167 (about 13%) are due to human errors and 1,142 (about 87%) due to technical failures. These incidents are economically costly in terms forgone revenue and capacity loss. Nevertheless, nuclear plants appear to be unequally prepared to avoid them; those located farther away from the regional NRC office are significantly more likely to experience an incident. This result holds controlling for several factors including reactors' age, technology (i.e., pressurized water or boiling water), and time effects. Importantly, we find that geographic proximity has a much larger effect on human-related incidents than technical incidents. Put differently, reactors farther away from the regulator display significantly more safety incidents that can be traced back to poor human performance and lack of adherence to safety management rather than to technical failure. In terms of magnitude, the expected number of human-related incidents increases by about 170% for reactors located in the upper quartile of travel distance (more than approximately 125 miles away from the regional NRC office).

As argued earlier, these results may occur because resident inspectors' monitoring suffers from being distant from the regional office or because plant employees represent the only source of social interactions for inspectors in remote areas, and this, in turn, impairs their objectivity in monitoring. While it is hard to tease apart these explanations, we show that our results hold by controlling for population density in the plants' surroundings (arguably capturing the extent of social opportunities). This control helps to rule out that remoteness per se, rather than distance to the regulatory office, drives our findings. We also validate that our results are specifically driven by the distance from the location of the regional NRC office rather than the distance from any large city.

To probe into the mechanisms explaining why longer travel times from the NRC regional office translate into more frequent nuclear incidents, we study the assignment of resident inspectors to the nuclear plants they oversee as a function of geographic distance and individual inspector experience. Our analysis reveals a negative relationship between inspectors' tenure (i.e., years worked at the NRC) and distance of the plants they oversee from their regional NRC office. That is, less-experienced inspectors tend to be assigned to more distant nuclear plants, whereas more experienced inspectors tend to be assigned to plants closer to the regulatory office. This finding is in line with the notion that information on regulatory protocols matters a great deal for the decentralized monitoring of nuclear reactors: to the extent that less experienced inspectors possess less information on regulatory protocols and nuclear plant characteristics, the assignment of those inspectors to plants located far away from the regulatory office provides an explanation for the below-par safety performance of those plants.[3]

Finally, to gauge the importance of inspectors' experience and knowledge about regulatory protocols on safety standards, we establish the impact of the arrival of a new resident inspector (following the turnover of another inspector) on employees' emergency training. If proximity to the regulator improves nuclear safety by aiding the quality of inspectors' monitoring, the effect should be larger for inspectors with less work experience, who are expected to benefit more from knowledge and inputs from the regional office. Vice versa, proximity to the regional office should be less relevant for inspectors with extensive knowledge on the design of nuclear plants and regulatory protocols. Estimating within-reactor regressions which compare the before and after-turnover periods, we show that, on average, the emergency training of nuclear plant employees does not change upon the arrival of a new resident inspector. However, there is a significant and negative change in emergency training when a less-experienced inspector arrives at a distant plant. We view this result as supporting the notion that proximity to the regulatory office aids regulatory monitoring, and that this effect is, as is intuitive, stronger for less-experienced inspectors who work at plants far from the regional office. Importantly, this result is not driven by pre-existing trends (i.e., less-experienced inspectors are not assigned to plants with declining employees' training prior to the turnover).

Our study offers several contributions to the literature. First, we expand a recent stream of research on regulatory monitoring and auditing. Extant works in this domain, from food-quality regulation to environmental audits, show that the accuracy of inspections is

[3]Notice that safety may decrease because less experienced resident inspectors at distant plants do not address and improve all possible shortcomings in the daily operation of a plant or because plant management downward-adjusts their decision to invest in safety training when expecting less strict oversight.

influenced by inspectors' biases and personal perceptions (Ibanez and Toffel, 2020), the technology used to carry out inspections (Jin and Lee, 2014), the incentive scheme to compensate inspectors (Duflo et al., 2013), and how regulators target plants for inspection (Duflo et al., 2018). While these works have identified significant variations in the design of regulatory monitoring and enforcement, we explore a novel source of this variation and unpack that: (1) proximity to regulatory offices and, arguably, easier access to information and best regulatory practice aids the monitoring process, and (2) inspector experience matters for safety compliance, especially for reactors that are distant to regulatory offices and where inspectors operate remotely from their office. In so doing, we also expand a growing stream of research on the role of proximity for the effectiveness of monitoring and governance (Ayers et al., 2011; Alam et al., 2014; Chhaochharia et al., 2012; Bernstein et al., 2016; Charoenwong and Umar, 2019; Giroud, 2013; Beck et al., 2019).

Moreover, we contribute to a relatively underdeveloped strand of research on safety management. Early works in this domain have studied safety in the airline industry (Golbe, 1986; Barnett and Higgins, 1989) or other specific industries such as healthcare (Kc and Terwiesch, 2009; Kuntz et al., 2015). The literature on safety in the nuclear power industry is limited to a handful of works which have studied the role of technological obsolescence (Bizet et al., 2022a), information disclosure (Feinstein, 1989; Bizet et al., 2022b), and market incentives (e.g., Hausman, 2014).[4] Our contribution to this stream of research is to highlight the role of regulatory monitoring in driving employees' training to sustain safety.[5]

We also relate to a recurrent debate about whether market incentives raise or hamper safety (Pagell et al., 2020).[6] This tradeoff is at the core of a large literature following the

[4]There is an older literature on nuclear safety following the Chernobyl disaster and the Three Mile Island accident; see David et al. (1996).

[5]This finding also adds to ongoing research on how firms' characteristics affect safety (see, e.g., Cohn and Wardlaw, 2016 and Cohn et al., 2021).

[6]On the one hand, if unsafe operation halts the production process, firms with insufficient safety procedures will have to forgo some profit. In this case, incentives to maximize profit and guarantee safe operations will align. On the other hand, investing in safety practices is costly and may hamper firm profitability (at

deregulation of many industries (see, e.g., Kennet (1993) for the airline industry). Because several nuclear plants today are privately owned and operate in competitive markets, whether or not market incentives can guarantee adequate safety remains an important question. In a seminal paper, Davis and Wolfram (2012) study the efficiency of nuclear plants following the deregulation of the US nuclear power industry. They find that nuclear plants operated commercially and subject to competitive pressures have higher operating efficiency than regulated plants. Focusing on safety, Hausman (2014) finds that the market incentives driven by ownership transfer and the removal of price regulation had a positive effect on safety.[7] Our evidence highlights that, while market forces can improve safety, the design of monitoring by regulatory agency remains a strong determinant of safety also for commercial reactors. This result contributes to an ongoing research on how to design regulation and auditing to increase compliance and minimize societal threats (Charoenwong and Umar, 2019; Auffhammer and Kellogg, 2011; Muehlenbachs et al., 2019; Duflo et al., 2013, 2018).[8]

2 Data and variables

2.1 Data sources

Our main data source consists of reactor-level information reported by the Nuclear Regulatory Commission (NRC), which is 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 publishes safety-related information for each commercially operating nuclear reactor in the US. First, for each reactor we gather data on safety incidents, so-called *initiating events*, which refer to situations in which technical

least in the short run). In this case, market forces per se may not promote safe operations and would require safety regulation (Hausman, 2014; Pagell et al., 2020).

[7] Lei and Tsai (2019) argue that the impact on incidents varies depending on how they are measured.

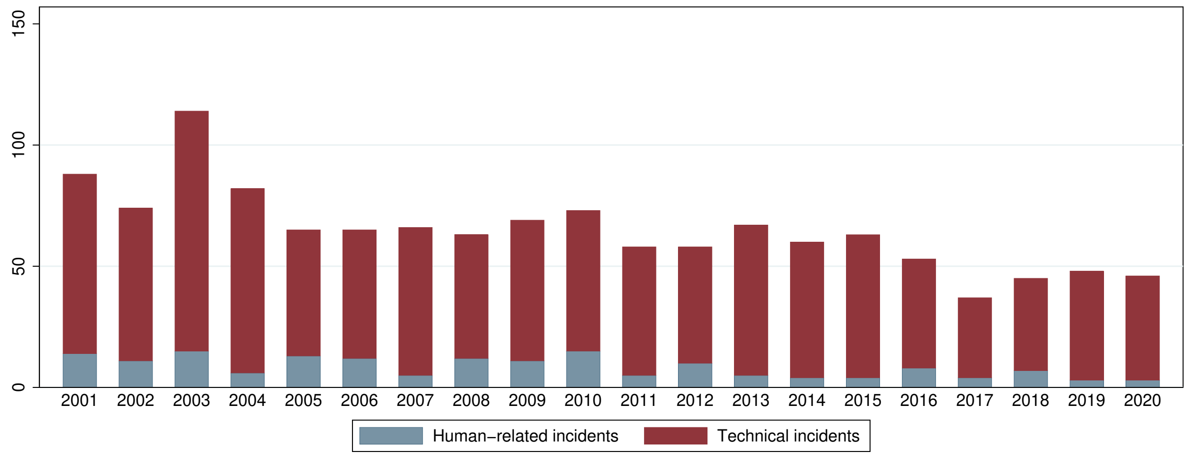
[8] On the design of regulatory audits with asymmetric information see Baron and Besanko (1984) and Laffont and Tirole (1986).

failure or human error has led to unanticipated reactor trips (i.e., interruptions of the nuclear chain reaction), resulting in unwanted power shortfalls during commercial operations. These events constitute safety violations that must be reported to the NRC. We collect all initiating events for the entire US nuclear power industry from the beginning of 2001 to the end of 2020. We obtain data on 1,309 initiating events, including a short textual description for each of them. Throughout our sample period, there is substantial variation in the number of reported initiating events per reactor, which ranges between 1 and 34.

To distinguish the root cause for each incident, we parse their textual description and identify those of human nature. We follow the literature and rely on a set of keywords to determine if the event, entirely or partially, was caused by human actions (see Gentzkow et al. (2019) for a review of text algorithms). Specifically, we screen event reports for language tokens as “human error”, “human performance”, “operator error”, “operator performance”, “training”, or “inadequate procedure”. This allows us to separate incidents associated with human factors from those linked to technical failures. After this extensive textual analysis, we identify 167 incidents related to human errors, which make up about 13% of all 1,309 incidents. In our analysis, we denote these initiating events as “human-related incidents”. Figure A.1 in the Appendix presents an example of an event classified as a human-related incident; the text at the bottom of the report expressly mentions that some employees carried out unauthorized operations. In contrast, we refer to all remaining incidents as “technical incidents”, i.e., those that did not mention human performance issues in their event description. Figure A.2 in the Appendix presents an example of an event classified as a technical incident; the text illustrates the case of a fire occurring following high-high vibration alarms. Figure 1 below shows the frequency of the two types of incidents throughout our 20-year sample.

Next, we compile data on the assignment of the NRC resident inspectors to the plants they monitor. When the NRC assigns a new resident inspector to monitor a certain plant, the

Figure 1: Reactor incidents between 2001 and 2020. Human-related incidents are all reactor incidents where root causes were classified as human-related. Technical incidents are all incidents where the event description did not mention human performance issues.



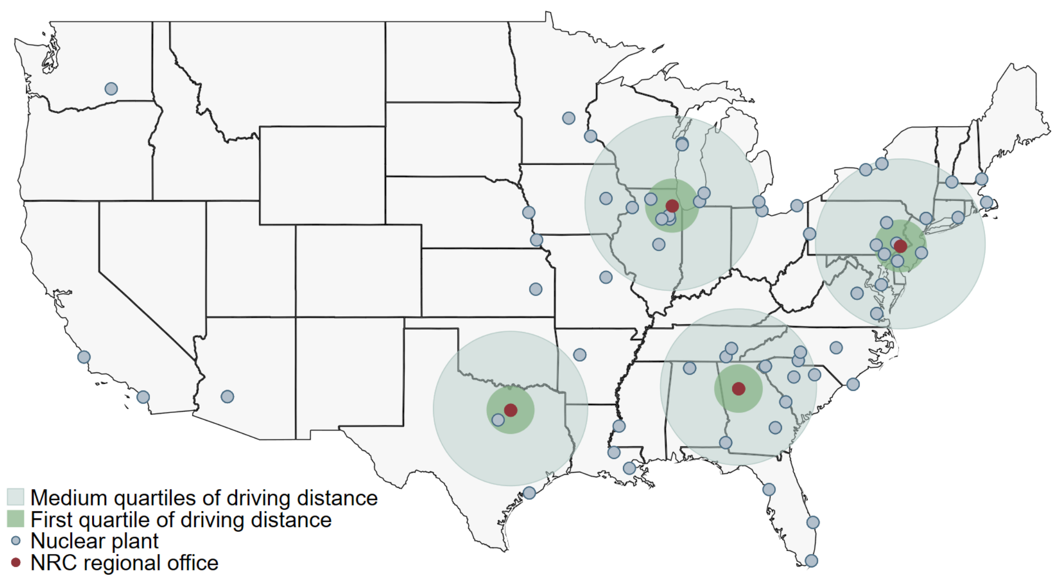
NRC publishes a web announcement that includes the plant's name, the incoming resident inspector's name, their start year at the NRC, and their college degree.[9] We use a web crawler program to collect information on this matching process between resident inspectors and reactors. In total, crawling this information yields data on the assignment of 414 resident inspectors to nuclear plants. For our analysis, we measure the experience of inspectors in terms of their years of tenure, which range from zero to 32 years. We categorize inspectors as either low-experienced or high-experienced based on whether their tenure falls below or above the median tenure of six years. Experience and on-the-job learning matter greatly for NRC inspectors, given the highly specialized nature of their tasks. Before their first assignment, each inspector undergoes an extensive training and qualification program with the NRC. Furthermore, all active inspectors must undergo continuous additional training.

Resident inspectors are assigned to plants by four regional NRC offices. Resident inspectors typically live in the communities around the reactors they oversee, which implies that

[9]NRC resident inspectors must not remain at any plant longer than seven years and are discouraged from participating in social activities involving plant employees. Any previously existing relationships with plant personnel or contractors must be disclosed.

they might live far away from the NRC regional office. We geo-code the location of each reactor and compute the travel time (in minutes) and the driving distance (in miles) from the reactor to its respective regional NRC office. We collect this information on travel time and driving distance using Google Maps. Figure 2 shows a map of all reactors in our sample (blue dots), that is, all 105 commercially operating reactors in the US between 2001 and 2020, as well as the four regional NRC offices (red dots). The circles surrounding the four offices display information on the distribution of travel distance. The first, smaller circles surrounding each NRC office display the first quartile of the empirical distribution of travel distance (0 to 125 miles). The second and larger circles display the two middle quartiles, i.e., quartiles two and three, of the distribution of travel distance (i.e., the second circles show the driving range from 125 to 404 miles). Finally, reactors outside of the range of the second circles lie in the fourth quartile of the distribution of travel distance (404 to 1,890 miles).

Figure 2: 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).



Finally, we gather data on the measures taken by management to improve the safety performance of their reactors' employees. Here, we conjecture that NRC monitoring through resident inspectors, by notifying management about misconduct and actions against regulatory protocols, shapes the safety performance of reactor personnel. Corrective actions to improve safety processes indeed are at the core of the activity of resident inspectors, who "visit control rooms and review operator logbook entries; watch operators conduct plant manipulations; visually assess areas of the plant; observe tests of, or repairs to, important systems or components; interact with plant employees to see if they have any safety concerns; and check corrective action documents to ensure that problems have been identified and appropriate fixes implemented." (Nuclear Regulatory Commission, 2022). Acquiring granular and time-variant data regarding staff quality and staff training is often challenging. In our study, we take advantage of the fact that the NRC systematically collects this data for each US nuclear plant. In particular, we utilize data on NRC-conducted periodic test drills for reactors' operating personnel.

The NRC conducts test drills four times a year, during which it assesses and scores the safety performance of each nuclear reactor's staff. These test exercises simulate emergency scenarios and evaluate the response capabilities of the operating personnel. The awarded score can range from 0 to 100, although scores below 90 are rarely awarded, essentially resulting in a 1 to 10 scale between a score of about 90 and 100. In our analysis, we refer to this measure as employees' emergency training. The data is directly available from the NRC's website as part of its oversight policy. We use the data series on emergency preparedness (EP01). Notice that these tests are supervised by the NRC's headquarters and local staff, including the plant's NRC resident inspector.

Because market incentives and plant ownership measures matter in this industry (as shown in Davis and Wolfram (2012) and Hausman (2014)), we also use these data. From the US Energy Information Administration (EIA), we collect monthly data on output and revenues at the reactor level.[10] Finally, we obtain data on further 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 "operator" and "owner", allowing us to consider whether control and ownership are separated, potentially weakening safety investment incentives. Thus, we label reactors as having a 'separate operator' when the majority owner differs from the reactor's operator. Additionally, reactors are labeled based on whether they have single or multiple owners, serving as an additional proxy for safety investment incentives. [11]

2.2 Summary statistics

Table 1 summarizes the data described above. Panel A shows the summary statistics for the 105 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 during our sample 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 (BWR). Moreover, Panel A presents location data for all 105 reactors and shows the respective distance to their corresponding regional NRC office. As shown earlier in Figure 2, the NRC conducts its activities through four regional offices, each responsible for a different geographical area within the US: the Northeast (situated in King of Prussia, PA), Southeast (based in Atlanta, GA), Northern Midwest (located in Lisle, IL), and Southern Midwest and West (located in Arlington, TX). The average travel time to a reactor from its respective regional office is 317 minutes, the average driving distance is 344 miles.

Panel B of Table 1 provides summary statistics on reactor size and personnel at each plant. Here, annual data yields around two thousand observations for the 105 reactors.

[10] We compute reactor revenue by evaluating reactor output by the respective monthly state-level retail electricity price, likewise published by the EIA.

[11] The EIA collects these data in EIA Data Forms 860, 861, and 923.

Table 1: Reactor characteristics.

	Mean	St. Dev.	Min	Max	Obs
A. Reactor age and location					
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
B. Reactor size, personnel, and emergency training					
Reactor size [MW]	1034.09	227.96	502.00	1,499.40	2,026
Reactor personnel [#]	1209.85	660.62	0	3,978	2,033
Emergency training [score]	96.93	1.86	88.70	100	7,513
C. Operational and ownership characteristics					
Average power [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
Single owner [Yes=1]	0.61	0.49	0	1	24,374

Panel A presents the age and distance to the corresponding 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. Panel B shows annual size and reactor personnel for all reactors in Panel A, as well as quarterly scores in regulatory emergency test drills. Panel C presents monthly reactor characteristics from 2001 to 2020, i.e., monthly average power (between 0 for no operation and 100 for operation at full capacity), monthly (net) generation, revenue (computed as monthly output multiplied with the respective monthly state-level retail price), whether a reactor is regulated or divested in a given month, whether the reactor is operated by a firm other than the majority owner, and whether a reactor has a single owner or multiple owners.

As shown, reactor size can vary, occasionally even within the same reactor due to capacity upgrades. Also, the number of personnel can vary considerably, both within a specific 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". Lastly, Panel B presents summary statistics on the test scores assigned by the NRC. The data are available every quarter, and this yields around seven thousand observations. Plants have an average score of almost 97 out of 100, though the score can vary considerably between a minimum of about 88 and a maximum of 100. In unreported analyses, we find that the score also varies between different reactors operated by the same owner.

Panel C presents the economic data for each 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 GWh, revenue (calculated by multiplying generation with the state-level electricity price), and three 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 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.[12] This variable allows to control for whether there exists a separate operator at the reactor-month level. Lastly, we collect data on whether a reactor has a single or multiple owners during a specific month. Arguably, when there is no distinct operator for a reactor or when there is a single owner only, there are more aligned incentives for maintaining safe operation. The final sample spans from 2001 to 2020 and comprises approximately 24,000 reactor-months observations for the 105 reactors in our sample. Notice that our sample is unbalanced in that 11 reactors exited the market while two reactors went online during the sample period.

3 Main results

This section demonstrates that despite the significant economic costs associated with nuclear incidents, they still occur, albeit not uniformly across plants.[13] We then examine the

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

[13]Incidents are also likely to generate negative externalities, which, however, are hard to estimate.

relationship between geographic proximity to regulatory offices and safety compliance.

3.1 Economic costs of reactor incidents

First, to measure the economic costs of incidents, we estimate the following regression:

$$Costs_{it} = \beta_0 + \beta_1 Incident_{it} + \beta_2 Age_{it} + \beta_3 Age_{it}^2 + \delta_t + v_i + \epsilon_{it}, \tag{1}$$

where the dependent variable $Costs_{it}$ is, depending on the specification, the average power or revenue of reactor i in month t. Our main estimate of interest is β_1, the coefficient for $Incident_{it}$. In our first specification, we use for $Incident_{it}$ the count of all incidents (human-related and technical incidents) at reactor i in month t. As control variables, the regression includes the reactors' age (and its squared term), month-year dummies to account for time-specific effects, δ_t, and reactor fixed effects, v_i, to remove constant heterogeneity at the reactor level. Standard errors are adjusted for heteroskedasticity.

Table 2 presents the findings. The coefficient for all incidents is negative and statistically significant at the one percent level: one additional incident is associated with a 16 percentage points drop in average reactor utilization in the corresponding month and an average drop in total revenues of about 11 million USD. In columns (2) and (3) we use human-related incidents and technical incidents, respectively, as independent variable. As can be seen, the estimates corroborate our findings and show that, in terms of magnitude, all incident types lead to significant and comparably large losses in capacity utilization and revenue. Notice that all results remain unchanged when clustering standard errors at the reactor-level to account for both heteroskedasticity and serial correlation.[14] In sum, the above figures highlight a strong negative relationship between incidents and plants' economic results. As incidents generate large economic costs, firms have clear incentives to avoid them (we study

[14] Arguably, serial correlation among incidents and within reactors can occur when one incident triggers additional future events.

Table 2: Economic costs of reactor incidents.

	(1) Power	(2) Revenue	(3) Power	(4) Revenue	(5) Power	(6) Revenue
All incidents	-15.906***	-11.417***				
	(0.638)	(0.509)				
Human incidents			-17.131***	-12.255***		
			(2.005)	(1.544)		
Technical incidents					-15.927***	-11.468***
					(0.678)	(0.546)
Age	-0.167	1.958***	-0.118	2.007***	-0.166	1.965***
	(0.169)	(0.150)	(0.168)	(0.150)	(0.170)	(0.151)
Age^2	0.004**	-0.006***	0.004**	-0.006***	0.004**	0.006***
	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
Month x Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Reactor FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,374	24,374	23,306	23,306	24,214	24,214

Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

firms' efforts to do so further below). However, nuclear incidents still happen despite these findings and require regulatory monitoring.

3.2 Geographic proximity and nuclear safety

This section contains our main findings concerning the role of proximity in monitoring and nuclear plants' safety. To explore this relationship, we first examine whether the likelihood of incidents decreases for plants located farther from the regional NRC office:

$$Incident_{it} = \beta_0 + \beta_1 Proximity_i + \beta_2 Age_{it} + \beta_3 Age_{it}^2 + \delta_t + \epsilon_{it}, \tag{2}$$

where the dependent variable $Incident_{it}$ captures, alternatively, the count of all incidents, human-related incidents, or technical incidents at reactor i in month t. On the right-hand side of the equation, we include the geographic proximity (in minutes of travel time and in miles to drive, depending on the specification) between the nuclear reactor and its regional NRC office, which represents our key explanatory variable. As before, the regression controls for reactors' age and its squared term, and month-year dummies to account for time-specific effects. Notice that this specification does not include reactor fixed effects because the distance between reactor sites and regional NRC offices does not vary over time. Depending on the specification, we include other controls, such as reactor technology, which may change the type of monitoring required, and the population surrounding a nuclear plant, which is useful to account for the effect of geographic remoteness on nuclear plants' safety. We compute standard errors clustered at the reactor-level to account for serial correlation in the residuals.

Table 3 contains our results obtained by estimating equation 2 with negative binomial regression. We operationalize geographic proximity using dummies corresponding to the bottom quartile, the two middle quartiles, or the upper quartile of its empirical distribution. In Column (1), we use the travel time (in minutes) as our proximity measure: benchmark reactors lie less than a two-hour drive away from the regulatory office (the first quartile runs up to 127 minutes of travel time); the dummy for travel time (medium) indicates whether a reactor lies more than two hours but less than about six hours away from the regulatory office (the third quartile runs up to 379 minutes of travel time); finally, the dummy for travel time (high) indicates whether a reactor falls in the upper quartile, so lies more than about six hours (379 minutes driving time) away from the regulatory office.

As shown in the first column, the expected number of incidents increases significantly for higher travel times. In terms of magnitude, the estimates suggest that the expected number of incidents roughly increases by 43% for reactors in the higher quartiles of travel time.[15] In Column (2) of Table 3, we perform a robustness test using driving distance (in miles) as a

[15]The percentage change in the expected number of counts can be approximated by $(e^{\beta} - 1) * 100$.

Table 3: Reactor incidents and proximity to regulatory office.

	All incidents		Human incidents		Technical incidents	
	(1)	(2)	(3)	(4)	(5)	(6)
Travel time (medium)	0.345**		0.994***		0.274**	
	(0.138)		(0.260)		(0.135)	
Travel time (high)	0.426**		0.998***		0.351**	
	(0.172)		(0.322)		(0.174)	
Miles to drive (medium)		0.332**		0.740***		0.286*
		(0.147)		(0.261)		(0.148)
Miles to drive (high)		0.392**		0.751**		0.338*
		(0.174)		(0.306)		(0.179)
Age	-0.049*	-0.048*	-0.080**	-0.074*	-0.041	-0.040
	(0.028)	(0.028)	(0.038)	(0.040)	(0.029)	(0.029)
Age^2	0.001	0.001	0.001	0.001	0.001	0.000
	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Technology	-0.261***	-0.286***	-0.637***	-0.672***	-0.213**	-0.238**
	(0.100)	(0.102)	(0.158)	(0.168)	(0.107)	(0.108)
Population	0.045***	0.046***	0.085***	0.081***	0.040***	0.041***
	(0.009)	(0.010)	(0.022)	(0.025)	(0.008)	(0.008)
Month x Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,374	24,374	23,306	23,306	24,214	24,214

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

proximity measure and obtain a similar result.

Our results are confirmed for both human-related incidents, in Columns (3) and (4), and technical incidents, in Columns (5) and (6). Notice, however, that the magnitudes of the estimates for human-related incidents are considerably larger than for technical incidents. The intuition here is that geographic distance shapes the quality of monitoring, which is more relevant for assessing human-related tasks thorough interactions with reactors' personnel and soft information derived by observing and evaluating employees carrying out safety procedures. By contrast, the assessment of technical reliability is likely to be more standardized and based on hard criteria. In terms of magnitude, the expected number of human-related incidents increases by about 170% for reactors located in the higher quartiles of travel time. Our findings offer compelling evidence that proximity is a critical factor for the human nature of nuclear safety.

As argued before, safety regulation is organized similarly across nuclear plants, especially with the audit processes and the frequency of audits. The major difference in the monitoring across plants is the resident inspectors. That distance matters suggests that monitoring becomes weaker because resident inspectors living close to a nuclear plant lack information and regular feedback from their regional office (we test this mechanism further below). A competing explanation is that resident inspectors at those typically remote locations may form stronger social ties with nuclear plants' personnel, and hence their monitoring is less strict. To tease apart these explanations, our results in Table 3 include a variable that controls for the population (in millions inhabitants) within a 50-mile radius surrounding a nuclear plant. This variable arguably proxies for the social opportunities of resident inspectors. As can be seen, our finding on geographic distance withstands the inclusion of this control variable.

In Tables A.1 through A.3 of the Appendix, we present several robustness tests that further corroborate our findings. Again, we find strong evidence for the effect of proximity on human-related incidents and effects of smaller magnitude and lower significance for technical incidents. First, in Column (1) of each table we include as additional control variable the driving distance to the largest city of the state where a nuclear plant is located. Including this control, which does not have a significant impact itself, confirms that our results are driven by the distance to the NRC regional office rather than merely the distance to larger cities (where NRC offices are typically located in or close to). Next, in Columns (2) to (4) we include a host of control variables at the reactor level, namely reactor's personnel, net generation, and nameplate capacity. These are useful to alleviate concerns of omitted factor bias related to the complexity of nuclear plants' operations. Importantly, including these controls does not alter the significance of the main finding. In Columns (5) through (7), we introduce a set of control variables pertaining to the corporate governance of the reactors: a binary variable set to one if the reactor has been divested, a binary variable set to one when the operator of the reactor is a different entity as the owner, and a binary variable set to one when the reactor has a single owner as opposed to multiple owners. The first variable captures whether a reactor is owned by a commercially operating independent power producer or a regulated utility, the second captures the potential impact of separating ownership and control, and the third captures the potential impact of ownership concentration. As shown, our results withstand the inclusion of these control variables. Last, in Column (8) we show that our result holds once we use a logit regression and a dependent variable equal to one if at least one (human-related) incident occurred in a given reactor-month and zero otherwise. Collectively, these tests confirm that nuclear plants more distant from regional regulatory offices exhibit below-par safety compliance and that this result is strongest for human-related incidents.

4 Mechanism testing

This section explores the potential mechanisms by which (i) longer travel times to the regulatory office translate into weaker monitoring, and (ii) weaker monitoring leads to a reduction of the plant management's safety efforts.

4.1 The matching of inspectors and nuclear reactors

This section first explores how longer travel times to regulatory offices may translate into weaker on-site monitoring. Recall that each nuclear plant in the US is monitored by at least two resident inspectors who spend a significant amount of time on the reactor site, obtaining information on the daily operations and reporting reactor status to the NRC.

Given our above finding on the spatial differences in reactor safety, we study the assignment of resident inspectors to reactors as a function of geographic distance and individual inspector experience. To implement these tests, we use the information on new assignments published by the NRC every time a new resident inspector is assigned to a plant. From these announcements, we obtain the tenure of each inspector, i.e., the year in which the inspector joined the NRC. This information allows us to create a variable that captures the experience (measured in years worked at the NRC) of all resident inspectors assigned to plants from 2001 to 2020. We obtain information on 412 inspector assignments.[16]

Specifically, we adopt as dependent variable a dummy set to one if a plant is located in the first quartile of the distribution of travel time and set to zero for plants located in higher quartiles (as shown earlier, there is a significant difference between the first and higher quartiles). As the main explanatory variable, we use the years of tenure an inspector has. We add our typical set of control variables that pertain to the reactor characteristics. Finally, we also control for inspector characteristics, i.e., the college degree and the rank and pay of inspectors. Moreover, we control for month-year fixed effects and NRC-region fixed effects to reduce time and geography effects common to all plants.[17]

As can be seen in Column (1) of Table 4, inspector tenure is negatively associated with the distance between the regional NRC office and the plant. Each regional NRC office tends to assign less experienced inspectors to plants farther from their office location. In terms of magnitude, one additional year of tenure is associated with a six percent decline in the likelihood of being assigned to a plant in the upper quartiles of travel time. This result withstands the inclusion of age, plant technology, educational attainment, and job rank as controls. Importantly, the estimates remain robust when controlling for the population (in

[16]Five inspector assignments were dropped from the analysis due to missing information information in work experience.

[17]By including fixed effects for the four regional NRC offices, we, in essence, estimate the assignment processes of inspectors within each office.

Table 4: Inspector tenure and proximity to regulatory office.

	High travel time			Logarithm of travel time		
	(1)	(2)	(3)	(4)	(5)	(6)
Tenure	-0.059***	-0.056**	-0.059***			
	(0.022)	(0.023)	(0.022)			
Logarithm of tenure				-0.195**	-0.161**	-0.174**
				(0.083)	(0.080)	(0.080)
Population		-0.141***			-0.030***	
		(0.026)			(0.007)	
Distance to city			0.029			0.167*
			(0.205)			(0.097)
Age	0.106	0.128	0.106	0.005	0.005	0.014
	(0.090)	(0.094)	(0.091)	(0.046)	(0.043)	(0.047)
Age^2	-0.001	-0.001	-0.001	0.000	0.000	-0.000
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Technology	1.114***	0.933***	1.115***	0.280**	0.199	0.287**
	(0.256)	(0.273)	(0.257)	(0.130)	(0.126)	(0.127)
Bachelor degree	-0.811	-0.984*	-0.815	-0.585***	-0.561***	-0.589***
	(0.551)	(0.589)	(0.552)	(0.219)	(0.214)	(0.216)
Master degree	0.106	0.286	0.105	0.140	0.170	0.126
	(0.257)	(0.281)	(0.257)	(0.111)	(0.106)	(0.110)
Senior inspector	0.412	0.203	0.408	0.354**	0.301**	0.332**
	(0.283)	(0.297)	(0.284)	(0.142)	(0.139)	(0.139)
Month x Year FE	No	No	No	Yes	Yes	Yes
Observations	412	412	412	407	407	407

Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Column (2)) and the distance to the largest city in the state where a reactor is located (in Column (3)). These controls are useful to rule out that the NRC assigns more experienced inspectors to plants located near population centers that demand an increased safety focus. For further robustness tests, in Columns (4) through (6), we rerun our tests using the continuous travel time (in minutes, in logs) between the regional NRC office and the plant that an inspector is assigned to. The finding indicates that more experienced inspectors tend to be assigned to reactors in close proximity to the NRC offices. Vice-versa, inspectors with less work experience tend to be assigned to more distant plants.[18]

These findings are in line with the notion that information on regulatory protocols matters a great deal for the decentralized monitoring of nuclear reactors. To the extent that less experienced inspectors possess less information on regulatory protocols and nuclear plant characteristics, the assignment of those inexperienced inspectors to plants located far away from the regulatory office provides an explanation for the below-par safety performance of those plants.

4.2 Inspector experience and firms' safety efforts

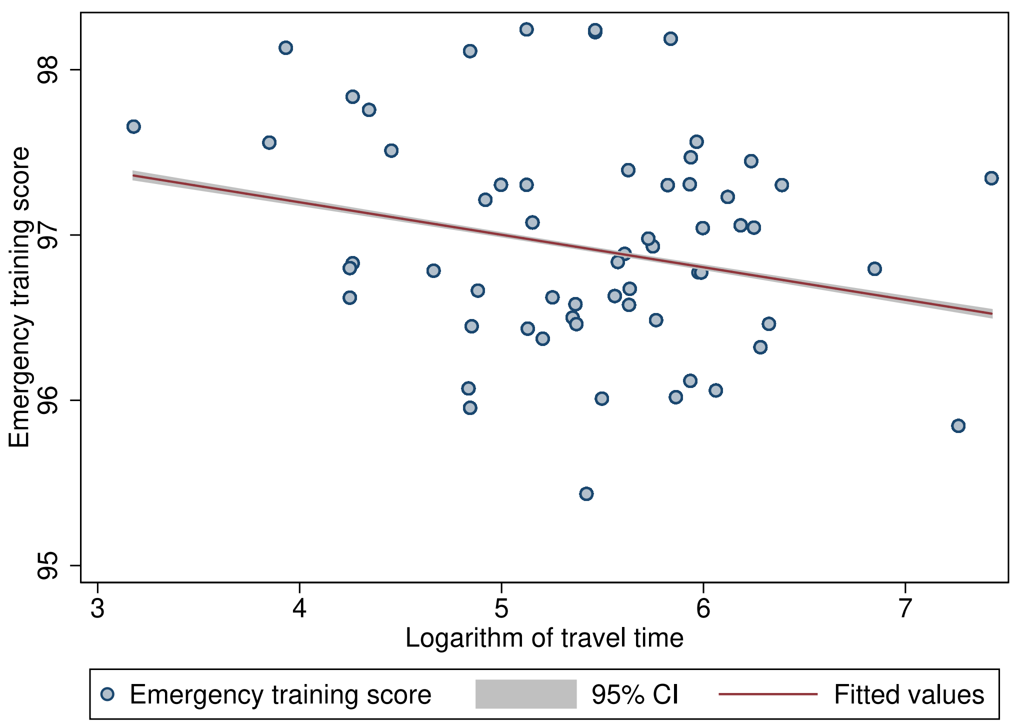
Next, we exploit the longitudinal dimension of the data to establish the impact of the arrival of new inspectors (with different work experience) on reactor safety. Because reactor incidents are rare events, tracing back the arrival of a new inspector to the likelihood of incidents is empirically challenging. To better assess the effects of inspector experience on nuclear safety, we therefore first explore the channel through which resident inspectors may, in fact, alter plant management's safety efforts and performance.

Resident inspectors, on a daily basis, obtain information from the reactor control room and immediately notify the plant management of safety issues that might occur. Hence, they have an immediate impact on the safety performance of reactor personnel. For our tests, we therefore utilize data on the emergency training of the reactor personnel, measured by the regulator itself through on-site drills. Figure 3 maps the scores of the emergency training exercises of a given reactor, averaged over the sample period, and the distance (miles, in logs) to the corresponding regional NRC office. As shown, the data indicate a negative

[18]These results hold if we use the logarithm of tenure as explanatory variable.

association between the scores for emergency training and distance to the regulatory office. This suggests that, as monitoring becomes weaker for plants located far away from the regulator, so does the emergency performance of the reactors' employees—either because less experienced resident inspectors at distant plants do not identify and improve all possible shortcomings in the daily operation of a plant and/or because plant management downward-adjusts their decision to invest in safety training when expecting such less strict oversight. In Table A.4 in the Appendix, we show that the negative relationship shown in Figure 3 is robust to regressing with OLS the emergency training scores on our previously used distance measures.

Figure 3: Emergency training and distance to regulatory office. Blue circles show the average emergency training score of a reactor during our sample. Travel time is the driving time (in minutes) from a reactor to its corresponding regional NRC office. The red line plots a linear fit.



For our final tests, we thus utilize the information on emergency training scores and inspectors' turnover. In particular, we exploit the arrival of a new inspector (due to turnover of the previous one; recall that inspectors must stay at most seven years at any plant) and use the quarterly data on employee training before and after such arrival. From the 412 inspector assignments used in Table 4, we exclude 28 due to either the simultaneous assignment of multiple inspectors or the assignment of different inspectors at adjacent points in time. This leaves us with 384 inspector assignments, corresponding to 1,070 reactor-quarter observations. This analysis allows the removal of reactor-specific heterogeneity via fixed effects.

Hence, the analysis captures within-reactor changes in employees' emergency training in the period surrounding the entry of a new inspector. We select three quarters surrounding the arrival to avoid contamination from subsequent turnovers.[19] In our baseline specification, we estimate

$$\begin{aligned} Emergency\ training_{it} = \beta_0 + \beta_1 Post\ turnover_{it} + \beta_2 Post\ turnover_{it}\ x\ low\ experience_{it} \\ + \beta_3 Age_{it} + \beta_4 Age_{it}^2 + v_i + \delta_t + \epsilon_{it}, \end{aligned} \tag{3}$$

where $Emergency\ training_{it}$ is the awarded training score for reactor i in quarter t and the variable $Post\ turnover_{it}$ is set to zero for the quarter before the arrival of a new inspector at plant i and set to one for the two subsequent quarters, i.e., the period post the arrival. Our main coefficient of interest is β_2, which estimates the differential effect for the arrival of an inspector with low experience compared to the arrival of an inspector with high experience. We again include controls for the age of a reactor, reactor fixed effects v_i, and quarterly time

[19]When including additional quarters pre- and post-arrival, identification may be contaminated through the arrival of a further resident inspector at the same plant either in the pre- or post-period. Whenever the two inspectors arrived simultaneously at a plant during the same month, we dropped these observations to have a clearer identification of each arriving inspector. In total, we have 166 cases where a low-experienced inspector (i.e., with less than six years of experience) arrived and 218 cases where an experienced inspector (i.e., with at least six years of experience) arrived. Notice that focusing on a shorter period surrounding inspector arrivals also aids us in ruling out potential effects of weaker monitoring through forming social ties with reactor employees.

fixed effects δ_t.

Column (1) of Table 5 presents the results. First, notice that the arrival of an inspector with high experience does not have a significant impact on employees' emergency training, as shown by the insignificant estimate of 0.117 for the benchmark of experienced inspectors. However, the differential effect for the arrival of an inexperienced inspector is significant and, on average, is associated with a decline in emergency training scores of 0.417 (roughly one-fourth of a standard deviation).

Table 5: Arrival of inspectors with low/high experience at close/distant reactors.

	Emergency training		
	(1)	(2)	(3)
Post turnover	0.117	-0.006	-0.169
	(0.098)	(0.104)	(0.111)
Post turnover x low experience	-0.417**	-0.428**	0.195
	(0.171)	(0.174)	(0.372)
Post turnover x far		0.157	0.368**
		(0.123)	(0.156)
Post turnover x low experience x far			-0.724*
			(0.420)
Age	-0.029	-0.029	-0.032
	(0.059)	(0.059)	(0.058)
Age^2	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)
Quarter x Year FE	Yes	Yes	Yes
Reactor FE	Yes	Yes	Yes
Observations	1,070	1,070	1,070

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

In Column (2), we add a second interaction term, *Post turnover x far*, to estimate the differential effect for inspector turnovers at plants far away from the regulatory office. As shown, a turnover per se occurring at a distant or nearby plant does not significantly affect the emergency training of reactor personnel.

Finally, in Column (3), we condition on whether a turnover occurs at a far or nearby plant *and* whether the arriving inspector has low or high work experience. The main finding here is that the difference in inspector experience exclusively matters for plants located far away from the regulatory office: The arrival of an experienced inspector at a distant plant is associated with an increase in emergency training, whereas the arrival of a less experienced inspector is associated with a decline in employees' training score. To rule out that less-experienced inspectors are assigned to distant plants with decreasing training scores, we test for differences in the training scores of those reactors but do not find statistically different trends. The results are shown in Table A.5 in the Appendix, where we test for differences in emergency training scores in the two quarters before the arrival of an inspector as compared to the quarter of arrival.

In sum, these findings provide evidence that the information and work experience that an inspector possesses are pivotal for proper monitoring, especially so when working at plants located remote from the regulatory office. Vice versa, information flows from and to peers working close to the regulatory office facilitates monitoring, and no significant differences between experienced and inexperienced inspectors exist.[20] Finally, the above results suggest that a reallocation of experienced (less experienced) inspectors to distant plants (in close proximity) to the regulatory office could enhance regulatory oversight and, ultimately, the safe operation of nuclear reactors.

5 Conclusion

A growing literature in economics focuses on the importance of safety regulation for employees and external stakeholders. In this paper, we have focused on safety in the nuclear power

[20] For recent evidence on the benefits of feedback and knowledge sharing among co-workers, see Emanuel et al. (2023).

industry. In many countries, the nuclear power industry represents a significant source of electricity generation. Nuclear energy, however, remains highly controversial given its safety concerns. Using rich data covering the universe of US nuclear plants, we provided several novel results to this literature.

To start, we show that nuclear plants located farther away from the regional NRC office have a significantly higher probability of experiencing incidents, especially those stemming from human causes. As we discussed, the US fleet of nuclear power plants is monitored by resident inspectors who live in the surroundings of the nuclear plants for a fixed amount of time. This unique feature of our setting, which differs from other regulatory contexts studied in the geographic proximity literature, suggests two potential interpretations behind our findings. First, resident inspectors assigned to plants far away from the regional NRC office (and thus distant themselves from colleagues) have less access to peers' knowledge and information. Second, resident inspectors in remote plants (which are more likely to be located far away from the regional NRC offices) lack social opportunities and thus end up becoming friends with the plant employees in turn losing objectivity in monitoring. We ruled out this latter explanation by using a set of control variables that captures how densely populated is the area around each nuclear plant. Evidence consistent with the first explanation also comes from our analysis of the job assignment of NRC inspectors to nuclear plants. We find that less experienced inspectors are assigned more often to plants that are farther away from the regional regulatory office, and the arrival of a new inspector with limited experience is associated with a decline in employees' emergency training at the nuclear plant.

Taken together, our results suggest that firms per se may not be able or willing to adopt the highest level of organizational practices to avoid incidents. Had this been the case, incidents would have occurred randomly as a function of external factors. However, our results indicate that incidents are a function of proximity to the regulator. Hence, regulation and monitoring matter a great deal. However, our study suggests that inspectors' monitoring is not uniform across plants, as it appears to be shaped by the geographic proximity to the regional NRC office and the different allocation of inspectors across space. Decentralizing monitoring via resident inspectors has the advantage of facilitating access to local information on the regulated firms but it faces other types of disadvantages harmful for monitoring. This result, which is connected to earlier findings on the effectiveness of local monitoring (e.g., Kedia and Rajgopal, 2011) as well as on the problems of increased distance between auditing offices (e.g., Beck et al., 2019), provides useful insights to the debate on how to design regulatory practices to improve enforcement and deterrence (Muehlenbachs et al., 2019).

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Appendix

Figure A.1: Example of initiating event report classified as human-related incident.

NRC FORM 366 (01-2014) U.S. NUCLEAR REGULATORY COMMISSION

LICENSEE EVENT REPORT (LER)
(See Page 2 for required number of digits/characters for each block)

APPROVED BY OMB: NO. 3150-0104 EXPIRES: 01/31/2017

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 Infocollects.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 means 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			8. OTHER FACILITIES INVOLVED	
MONTH	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REV NO.	MONTH	DAY	YEAR	FACILITY NAME N/A	DOCKET NUMBER N/A
10	12	2014	2014 -	006	- 01	08	11	2015	FACILITY NAME N/A	DOCKET NUMBER 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)(i)	☐ 50.73(a)(2)(i)(C)	☐ 50.73(a)(2)(vii)
	☐ 20.2201(d)	☐ 20.2203(a)(3)(ii)	☐ 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)(i)	☐ 50.36(c)(1)(i)(A)	☐ 50.73(a)(2)(iii)	☐ 50.73(a)(2)(ix)(A)
10. POWER LEVEL	☐ 20.2203(a)(2)(ii)	☐ 50.36(c)(1)(ii)(A)	☒ 50.73(a)(2)(iv)(A)	☐ 50.73(a)(2)(x)
	☐ 20.2203(a)(2)(iii)	☐ 50.36(c)(2)	☐ 50.73(a)(2)(v)(A)	☐ 73.71(a)(4)
1%	☐ 20.2203(a)(2)(iv)	☐ 50.46(a)(3)(ii)	☐ 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)(i)(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	MANU-FACTURER	REPORTABLE TO EPIX	CAUSE	SYSTEM	COMPONENT	MANU-FACTURER	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	MONTH	DAY	YEAR
☐ YES *(If yes, complete 15. EXPECTED SUBMISSION DATE)* ☒ NO		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.

NRC FORM 366 (01-2014)

Figure A.2: Example of initiating event report classified as technical incident.

NRC Form 366 (9-2007) — U.S. NUCLEAR REGULATORY COMMISSION	APPROVED BY OMB: NO. 3150-0104 — EXPIRES 08/31/2010
LICENSEE EVENT REPORT (LER) (See reverse for required number of digits/characters for each block)	Estimated burden per response to comply with this mandatory collection request: 50 hours. Reported lessons learned are incorporated into the licensing process and fed back to industry. Send comments regarding burden estimate to the Records and FOIA/Privacy Service Branch (T-5 F52), U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by internet e-mail to infocollects@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 means 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
Donald C. Cook Nuclear Plant, Unit 1	05000315	1 of 5

4. TITLE

Manual Reactor Trip Due To Main Turbine High Vibration

5. EVENT DATE			6. LER NUMBER			7. REPORT DATE			8. OTHER FACILITIES INVOLVED	
MONTH	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REVISION NUMBER	MONTH	DAY	YEAR	FACILITY NAME	DOCKET NUMBER
09	20	2008	2008	-- 006 --	01	05	06	2009	FACILITY NAME	DOCKET NUMBER

9. OPERATING MODE: 1

10. POWER LEVEL: 100

11. THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: (Check all that apply)

☐ 20.2201(b)	☐ 20.2203(a)(3)(i)	☐ 50.73(a)(2)(i)(C)	☐ 50.73(a)(2)(vii)
☐ 20.2201(d)	☐ 20.2203(a)(3)(ii)	☐ 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)(i)	☐ 50.36(c)(1)(i)(A)	☐ 50.73(a)(2)(iii)	☐ 50.73(a)(2)(ix)(A)
☐ 20.2203(a)(2)(ii)	☐ 50.36(c)(1)(ii)(A)	☒ 50.73(a)(2)(iv)(A)	☐ 50.73(a)(2)(x)
☐ 20.2203(a)(2)(iii)	☐ 50.36(c)(2)	☐ 50.73(a)(2)(v)(A)	☐ 73.71(a)(4)
☐ 20.2203(a)(2)(iv)	☐ 50.46(a)(3)(ii)	☐ 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 Specify in Abstract below or in NRC Form 366A
☐ 20.2203(a)(2)(vi)	☐ 50.73(a)(2)(i)(B)	☐ 50.73(a)(2)(v)(D)	

12. LICENSEE CONTACT FOR THIS LER

FACILITY NAME	TELEPHONE NUMBER (Include Area Code)
John A. Zwolinski, Regulatory Affairs Manager	(269) 466-2478

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

14. SUPPLEMENTAL REPORT EXPECTED			15. EXPECTED SUBMISSION DATE	MONTH	DAY	YEAR
X	YES (If Yes, complete EXPECTED SUBMISSION DATE).	NO		02	26	2009

ABSTRACT (Limit to 1400 spaces, i.e., approximately 15 single-spaced typewritten lines)

On September 20, 2008, at 2005 hours, Donald C. Cook Nuclear Plant Unit 1 control room operators initiated a manual reactor trip from 100% power following high-high vibration alarms on all main turbine supervisory instrumentation vibration points. In addition, numerous alarms on components in the condensate and feedwater flowpaths along with severe vibration and rumbling were noted by control room operators.

Upon the reactor trip, all control rods fully inserted, the Auxiliary Feedwater System (AFW) and other major plant components functioned as designed. The main generator was reported to be on fire, and the Shift Manager declared an Unusual Event (UE) when the fire was not extinguished within 15 minutes. The fire was declared extinguished at 2028 hours. At 2044 hours, the operators tripped closed the Main Steam Isolation Valves (MSIV) in accordance with procedure. Closure was based on an observed cooldown of the Reactor Coolant System (RCS). RCS temperature recovered following closure of the MSIVs.

The reactor trip, UE, AFW actuation, and MSIV closure were reported in accordance with 10 CFR 50.72(b)(2)(iv)(B), 10 CFR 50.72(a)(1)(i), and 10 CFR 50.72(b)(3)(iv)(A). The reactor trip, AFW actuation and MSIV closure are reportable as a Licensee Event Report (LER) in accordance with 10 CFR 50.73(a)(2)(iv)(A).

The cause of the reactor trip was high-high vibration of the main turbine. Corrective actions have commenced and include repair of the main turbine and generator.

NRC FORM 366 (9-2007)

Table A.1: Reactor incidents and proximity to regulatory office, robustness tests.

	All incidents							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Travel time (medium)	0.345**	0.345**	0.149	0.342**	0.308**	0.356***	0.366**	0.368**
	(0.137)	(0.143)	(0.134)	(0.138)	(0.140)	(0.137)	(0.150)	(0.143)
Travel time (high)	0.427**	0.422**	0.181	0.426**	0.336*	0.399**	0.442**	0.414**
	(0.172)	(0.176)	(0.169)	(0.173)	(0.182)	(0.170)	(0.180)	(0.173)
Age	-0.049*	-0.049*	-0.043**	-0.050*	-0.050*	-0.048*	-0.048*	-0.049**
	(0.028)	(0.028)	(0.019)	(0.029)	(0.027)	(0.027)	(0.027)	(0.021)
Age^2	0.001	0.001	-0.000	0.001	0.001	0.001	0.001	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Technology	-0.261***	-0.277***	-0.319***	-0.261**	-0.285***	-0.261***	-0.265***	-0.286***
	(0.099)	(0.106)	(0.104)	(0.101)	(0.101)	(0.099)	(0.099)	(0.100)
Population	0.045***	0.047***	0.058***	0.047***	0.051***	0.043***	0.044***	0.047***
	(0.010)	(0.009)	(0.015)	(0.011)	(0.010)	(0.009)	(0.009)	(0.010)
Distance to city	0.001							
	(0.073)							
Personnel		-0.000						
		(0.000)						
Generation			-0.002***					
			(0.000)					
Reactor size				-0.000				
				(0.000)				
Divested					-0.130			
					(0.108)			
Separate operator						-0.266**		
						(0.127)		
Single owner							0.089	
							(0.103)	
Month x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Observations	24,374	24,326	24,374	24,293	24,374	24,374	24,374	24,374

Columns (1) to (7) show results for negative binomial regressions. Column (8) shows results for a logit regression. Reactor-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.2: Human-related incidents and proximity to regulatory office, robustness tests.

	Human incidents							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Travel time (medium)	0.992***	1.072***	0.814***	1.005***	0.971***	1.000***	1.044***	0.995***
	(0.260)	(0.256)	(0.266)	(0.251)	(0.276)	(0.259)	(0.264)	(0.265)
Travel time (high)	0.997***	1.090***	0.737**	0.996***	0.946**	0.982***	1.038***	0.953***
	(0.322)	(0.327)	(0.331)	(0.319)	(0.382)	(0.323)	(0.315)	(0.330)
Age	-0.080**	-0.087**	-0.065	-0.078*	-0.080**	-0.080**	-0.076**	-0.073*
	(0.038)	(0.038)	(0.047)	(0.040)	(0.038)	(0.038)	(0.036)	(0.040)
Age^2	0.001	0.001	-0.000	0.001	0.001	0.001	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Technology	-0.637***	-0.520***	-0.685***	-0.618***	-0.650***	-0.635***	-0.640***	-0.645***
	(0.158)	(0.176)	(0.175)	(0.153)	(0.160)	(0.158)	(0.160)	(0.163)
Population	0.086***	0.091***	0.099***	0.078***	0.088***	0.084***	0.082***	0.090***
	(0.022)	(0.022)	(0.027)	(0.019)	(0.022)	(0.022)	(0.021)	(0.025)
Distance to city	0.019							
	(0.125)							
Personnel		0.000**						
		(0.000)						
Generation			-0.002***					
			(0.000)					
Reactor size				0.001				
				(0.001)				
Divested					-0.070			
					(0.202)			
Separate operator						-0.139		
						(0.218)		
Single owner							0.185	
							(0.190)	
Month x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Observations	23,306	23,258	23,306	23,228	23,306	23,306	23,306	23,306

Columns (1) to (7) show results for negative binomial regressions. Column (8) shows results for a logit regression. Reactor-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.3: Technical incidents and proximity to regulatory office, robustness tests.

	Technical incidents							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Travel time (medium)	0.274**	0.261*	0.079	0.266*	0.238*	0.284**	0.289*	0.286**
	(0.135)	(0.140)	(0.129)	(0.136)	(0.136)	(0.134)	(0.149)	(0.140)
Travel time (high)	0.351**	0.332*	0.110	0.349**	0.263	0.323*	0.363**	0.348**
	(0.173)	(0.177)	(0.169)	(0.175)	(0.180)	(0.172)	(0.183)	(0.175)
Age	-0.041	-0.040	-0.040**	-0.042	-0.043	-0.040	-0.040	-0.044**
	(0.029)	(0.029)	(0.019)	(0.030)	(0.028)	(0.028)	(0.028)	(0.022)
Age^2	0.001	0.000	-0.000	0.000	0.001	0.000	0.000	0.000
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)
Technology	-0.213**	-0.254**	-0.279***	-0.215**	-0.238**	-0.214**	-0.216**	-0.235**
	(0.113)	(0.108)	(0.109)	(0.108)	(0.106)	(0.107)	(0.107)	
Population	0.040***	0.041***	0.053***	0.042***	0.045***	0.038***	0.039***	0.041***
	(0.008)	(0.008)	(0.013)	(0.010)	(0.009)	(0.008)	(0.008)	(0.009)
Distance to city	-0.001							
	(0.072)							
Personnel		-0.000						
		(0.000)						
Generation			-0.002***					
			(0.000)					
Reactor size				-0.000				
				(0.000)				
Divested					-0.128			
					(0.108)			
Separate operator						-0.275**		
						(0.133)		
Single owner							0.067	
							(0.108)	
Month x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Observations	24,214	24,166	24,214	24,133	24,214	24,214	24,214	24,214

Columns (1) to (7) show results for negative binomial regressions. Column (8) shows results for a logit regression. Reactor-level clustered standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.4: Emergency training and proximity to regulatory office.

	Emergency training					
	(1)	(2)	(3)	(4)	(5)	(6)
Travel time (medium)	-0.369**	-0.382**	-0.354**			
	(0.169)	(0.170)	(0.158)			
Travel time (high)	-0.313*	-0.313*	-0.223			
	(0.178)	(0.179)	(0.177)			
Miles to drive (medium)				-0.447***	-0.461***	-0.370**
				(0.170)	(0.170)	(0.169)
Miles to drive (high)				-0.305*	-0.305*	-0.214
				(0.176)	(0.177)	(0.176)
Age			-0.028			-0.029
			(0.037)			(0.038)
Age^2			0.001			0.001
			(0.001)			(0.001)
Technology			-0.493***			-0.439***
			(0.132)			(0.136)
Quarter x Year FE	No	Yes	Yes	No	Yes	Yes
Observations	7,513	7,513	7,513	7,513	7,513	7,513

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

Table A.5: Pre turnover trends for inspectors with low/high experience at close/distant reactors.

	Emergency training	
	(1)	(2)
Turnover t-2	-0.016	0.012
	(0.108)	(0.093)
Turnover t-1	-0.036	0.014
	(0.084)	(0.049)
Turnover t-2 x far	0.044	
	(0.130)	
Turnover t-1 x far	0.068	
	(0.095)	
Low experience		-0.338**
		(0.160)
Turnover t-2 x low experience		0.008
		(0.133)
Turnover t-1 x low experience		0.009
		(0.082)
Age	0.000	0.000
	(.)	(.)
Age^2	0.001	0.001
	(0.001)	(0.001)
Quarter x Year FE	Yes	Yes
Reactor FE	Yes	Yes
Observations	1,082	1,082

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