Global Security - Howard H. Baker Jr. Center for Public Policy

The Consequences of Nuclear Facility Incidents

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Executive Summary

In this report, we discuss the direct and indirect economic and political costs and consequences of accidental or deliberate nuclear security incidents that occur at nuclear facilities. We start by discussing the potential economic consequences caused by an accident or attack at a nuclear facility. We examine the size of potential damages, and the scope of damages across time, and geographic region. In doing so, we examine both direct damages from an incident, such as deaths due to radiation exposure or increased electricity prices caused by shutting down a nuclear power facility, and indirect damages transmitted by social and behavioral channels, such as how risk perception about nuclear power changes at the consumer or government level after an incident at a nuclear facility. To estimate costs, we apply value of statistical life (VSL) estimates to the potential lives lost, damages to areas surrounding nuclear facilities using estimates of housing price declines, and the increased costs of generating electricity with alternative energy sources and the subsequent environmental consequences. To understand the potential costs of these consequences, we examine the Fukushima Daiichi disaster, Germany's nuclear energy policies in the post-Fukushima context, and the San Onofre Nuclear Generating Station closure. Based on these cases, we estimate that economic costs of closures due to deliberate or accidental incidents at nuclear facilities would be extremely high, totaling hundreds of billions of dollars.

The second section of this report outlines the potential political costs that are less tangible, but nevertheless can be quite costly for governments. Political consequences can be categorized into two main types – 1) political decision making about responses to incidents and 2) public opinion and political costs for governments. We begin by discussing how important the political decision-making process is when responding to security or disaster incidents, focusing on the quality of political leadership, quality of political institutions, and levels of trust in the government. The second politicized aspect to consider is the clean up and repair costs, as well as increased costs of building facilities with more effective security and safety designs to prevent further incidents. Governments must consider how much to spend on increased safety and security, weighing the demands of the public and the requests of the facility managers with government spending capabilities and government interests

The second type of political consequences is "domestic audience costs," which refer to declining public support for the government in response to incidents directly, and government policies about nuclear technology and risk. Political consequences in this regard involve negative public support of the governments at the local, regional, or national levels, protests, riots, and sometimes removal from office. Another major effect of public opinion political and social cost that could occur as a result of a nuclear incident is the emergence and/or spread of anti-nuclear social movements that challenge the government's use of nuclear facilities for energy, research, or weapons. Additionally, after such incidents, there will likely be significant policy discussions about the use of nuclear energy in particular, and whether such facilities are worthy of further investment by governments. We end with some policy implications and takeaways.

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1. Introduction

Since the 1957 U.S. Atomic Energy Commission released the report "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants,"[1] the majority of research conducted on consequences on nuclear incidents have focused on technical and medical consequences, particularly the effect of radioactive exposure to nearby populations. Here we diverge, focusing specifically on economic and political costs and consequences that are less commonly examined, but potentially as important and worthy of understanding.

2. Economic Costs & Consequences

Accidents at or attacks on nuclear facilities can have terrible human and economic consequences. In this section, we attempt to establish a distribution of the potential economic consequences caused by an accident or attack at a nuclear facility. We examine both the size of potential damages, and the scope of damages across time, and geographic region. In doing so, we examine both direct damages from an incident, such as deaths due to radiation exposure or increased electricity prices caused by shutting down a nuclear power facility, and indirect damages transmitted by social and behavioral channels, such as how risk perception about nuclear power changes at the consumer or government level after an incident at a nuclear facility.

Rather than developing a comprehensive model to value expected damage from a nuclear incident, we instead rely on case studies from previous incidents, such as the Fukushima Daiichi accident in March 2011. This approach offers several advantages. Fukushima and other incidents are well-studied, with multiple academic articles across social and hard science disciplines studying the after-effects of each incident. In addition, we need not rely on data availability for each hypothetical event, and can instead extrapolate lessons from actual historic incidents. In some cases, we have evidence of specific incidents, and use a simple framework to examine the potential losses had the incident been more severe. For example, the San Onofre Nuclear Generating Station (SONGS) in Southern California closed suddenly due to maintenance issues in January 2012, and the effect of this closure on electricity markets was studied in subsequent academic articles. We ask the question; What if SONGS had instead closed due to an accident terrorist attack? The effect on electricity markets may have been substantially the same, but an attack could have caused great damage in terms of lives lost and property value destroyed.

The following section details our methods for quantifying the potential damage caused by nuclear incidents. We then briefly discuss other modeling approaches before moving into a systematic review of academic case studies, noting key features of each incident and the follow-on behavioral effects.

2.1 Quantifying the Damage of an Incident

We attempt to quantify the size of damages from a nuclear incident by relying on pre-established and standard estimates of welfare losses. To quantify the economic damage of death and injury resulting from a nuclear incident, we apply value of statistical life (VSL) estimates to the potential lives lost. VSL essentially calculates the value that people place on their own lives in monetary terms. One common technique to estimate VSL is to compare wages for different occupations with different fatality rates, controlling for all other factors of an occupation (see Kneisner et al. for an example of this method.). VSL estimates tend to be quite high, with estimates over time and place ranging between $1 million to $25 million for a single lost life. We use a VSL estimate of $9 million, unless citing past work which uses their own estimate. $9 million is close to the estates employed by the US department of Transportation and Environmental Protection Agency (Dockins et al.) in 2020 dollars. Because VSL estimates are so large, lost lives tend to be the dominant driver of health-related welfare losses, as even a few lost lives can result in tens of millions of dollars in damages, swamping other damages related to disease and injury. Therefore, we limit our analysis of the health consequences of nuclear incidents to VSL losses, unless citing specific work in which a further health analysis was performed.

Damages to the area surrounding a nuclear facility after an incident are quantified using estimates of housing price declines. These "hedonic" estimates are commonly used to quantify the amenity value (or dis-value) of local environmental features, such as hazardous waste (see Greenstone 2008 for example). Since homes are such large and consequential purchase for most consumers, home prices tend to reflect information more fully about local amenity values than smaller and less important (or less permanent) purchases. This means that the perceived economic value of environmental damage to the area local to a nuclear incident should be captured by declines in local home prices. Of course, in extreme cases such as Chernobyl, nuclear incidents may render an area unlivable for a long time, completely erasing local property values, meaning that potential amenity damages from a nuclear attack in our analysis are effectively bounded above by the total property value within a contaminated radius.

Nuclear power facilities are large compared to other types of electricity generators, so shutting down nuclear facilities tends to significantly raise the cost of generating electricity. The welfare loss caused by increasing electricity prices is simply the difference in total generation costs before and after a nuclear facility is shut down. In addition to raising costs, shutting down nuclear facilities tends to shift generation to fossil fuels – either coal or natural gas generators. Burning fossil fuels causes the release of toxic emissions such as carbon dioxide, sulfur dioxide, and particulate matter, which can damage health and contribute to climate change. The cost of emissions is difficult to measure, since the marginal effect of additional emissions varies across time and space, and depends critically on tradeoffs between current and future consumption. The EPA estimates that the social cost of carbon (SCC) for 1 ton of carbon emissions in 2020 results in between $12 - $123, with an average of $42 per ton.

The potential damages to life, property, electricity markets, and the environment from a nuclear incident are extensive, but by no means exhaustive. For instance, a nuclear incident may result in hundreds of lost jobs, or damage the productivity of local agriculture. These damages may be large, but are often more difficult to estimate in dollar value than the losses discussed above. The welfare losses from lost jobs depend critically on how quickly and at what salary workers find new jobs, while it may be difficult to identify the value to society of lost agricultural production. Follow-on political effects after a nuclear incident may also cause significant economic harm if the actions taken by governments are ill-considered. Several case studies we cite discuss these damages, but it should be noted that it is difficult to include these in a welfare analysis, and therefore our estimates should be considered a lower bound on potential damages. Nevertheless, it should already be clear that the potential welfare losses are massive. A simple formula can establish the lower bound on welfare damage from a nuclear incident:

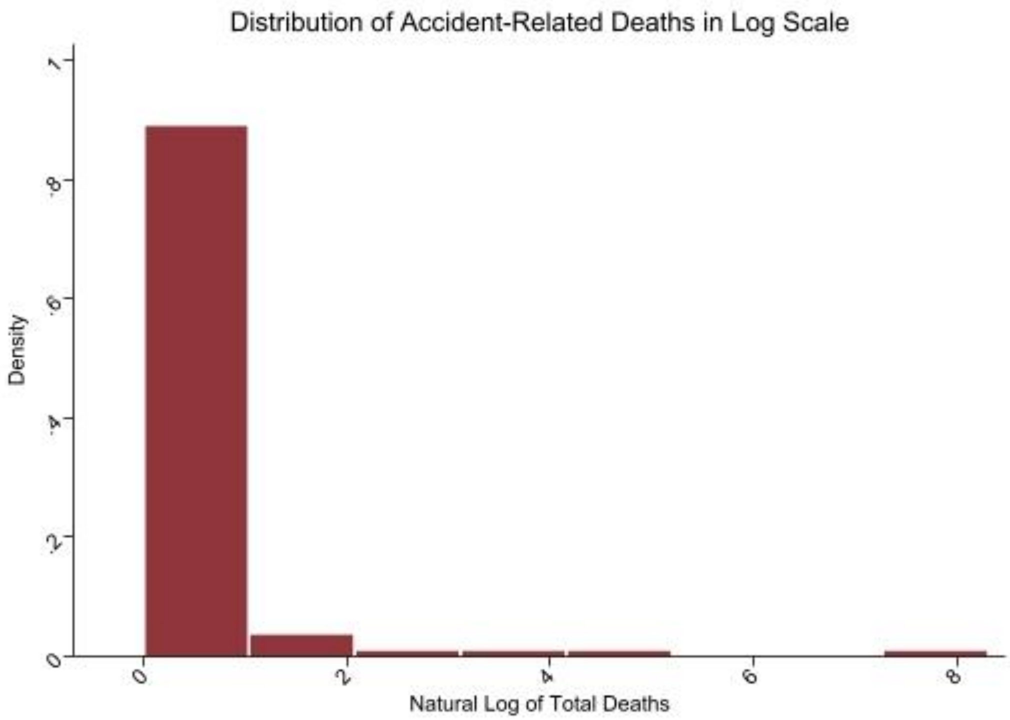
Total Damage = (# of deaths) x ($VSL) + ($ total property value losses) + ($ total increased electricity costs) + (total increased carbon emissions) x ($SCC) + $ remediation cost + $ unquantified cost

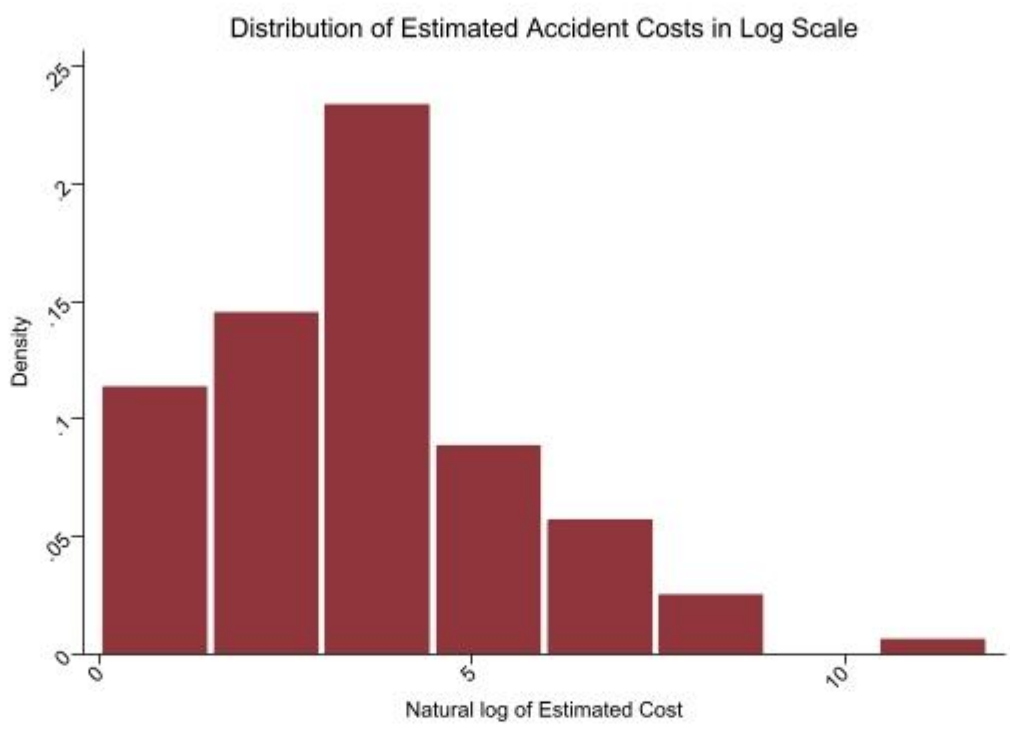
2.2 Comprehensive Modeling Approaches

Several other studies attempt to fully account for the damage caused by nuclear incidents. For example, Ashley et al. studies the effect of a hypothetical nuclear reactor accident occurring in southern England. The authors use the "PACE" (Probabilistic Safety Assessment Code) model to predict total population exposure to radioactive material, necessary shelter in place orders, evacuations, and iodine treatments for radiation exposure. The authors then use an economic costing model called "COCO-2" to quantify the total damages to health, agriculture, and local business under both low and high countermeasure intervention levels. Although the total costs estimated are site-specific to the chosen area in southern England, there are several notable findings which can be generalized. First, health costs dominate all other costs of nuclear accidents in this analysis, and the cost of fatalities is two to five times as high as all other health-related costs combined. In total, cancer fatalities account for 60-80% of all health-related costs, and health related costs account for 60-85% of total damages from a nuclear accident. This analysis is done for a range of possible accidents, rather than for a terrorist attack. Fatalities and health related damages may be even more prominent in a cost analysis of a terrorist attack, as deaths during an initial attack would be added to the total of health-related costs.

Notably, Ashley et al. assume that road networks in the southern UK will still be operable post-incident in their analysis. This may result in a large underestimate of potential damages. To see why, consider why such an incident may occur. Natural disasters or terrorist attacks may also cripple local infrastructure. A comprehensive analysis of risk should also account for damage to infrastructure outside of a nuclear facility which could complicate evacuation and remediation efforts.

The National Politics of Nuclear Power: Economics, Security & Government by Sovopol & Valentine includes a comprehensive list of accidents at Nuclear Power facilities between 1955 and 2011, along with the number of fatalities associated with the accident, and an estimate of the total cost of the accident. These cost estimates include "the total costs of destruction of property, emergency response, environmental remediation, evacuation, lost product, fines, and court and insurance claims". This is notably different than a traditional economic cost model in several dimensions, and notably does not include a value for lives lost. However, the distribution of fatalities and the estimated costs from attacks is informative. As shown in the histograms below, the distribution of both deaths and costs resulting from nuclear accidents demonstrates an extreme right skew, reflecting the difference between relatively minor accidents (although even these can cost tens of millions of dollars), and major accidents which can cost hundreds of billions of dollars and/or thousands of deaths. Note that these figures are in log-scale rather than linear-scale. We choose to visualize costs and deaths in this way due to the extreme right-skew of historic damages from nuclear incidents. On a log-scale histogram with values bounded below at 0, a normal distribution of costs and deaths would indicate a right skew of damages. These histograms demonstrate a significant right skew even in log scale, demonstrating an extremely skewed distribution of damages in which most incidents cause little damage, but a few are incredibly costly.





Taken together, past work on estimating the costs of nuclear incidents paints a consistent picture. Although incidents are rare with proper safety precautions, the costs are extremely uncertain, although we can say with certainty that costs to human health, and specifically fatalities, are likely to make up a large portion of the cost of any incident. Many incidents may result in "minor" damages, but the small possibility of extremely destructive accidents and attacks which cause thousands of deaths and could cost trillions of dollars looms large over any analysis of potential risks and costs of nuclear power. In fact, it is easy to imagine nuclear incidents worse than the costliest past incidents, such as Chernobyl or Fukushima. For this reason, it is important to analyze potential worst-case scenarios involving high casualty rates, cleanup costs, and complete property value losses in the vicinity of nuclear facilities.

2.3 Fukushima Daiichi

On Friday, March 11th 2011, a category 9 earthquake off the coast of Japan caused a 15 meter tsunami which struck the Fukushima Daiichi Nuclear Power Plant. The earthquake itself damaged the electricity grid which provided the plant with access to external power, and the tsunami subsequently disabled the backup generators, causing coolant systems at Fukushima to fail, resulting in meltdowns at three reactors. This sequence of events resulted in the worlds largest nuclear disaster since Chernobyl, as radiation was released into the atmosphere and Pacific Ocean, and over 150,000 local residents were evacuated from the radius around the facility, and over 35,000 of those residents remain evacuated as of 2021. Damage in Japan was not limited to the Fukushima nuclear facility.

Accounting for the cost of the Fukushima disaster is difficult, but highlights several important issues for future consideration. Can the effect of the disaster be disentangled from the effect of the policy response? Can the effect of the disaster at the nuclear facility be disentangled from the direct damage from the earthquake and tsunami? In short, No. All nuclear incidents will be followed by a policy response, so the policy response must be considered in conjunction with the incident itself. We also cannot analyze nuclear facilities as if they are isolated from surrounding populations and infrastructure. The Fukushima earthquake and tsunami did considerable damage to road, railroad, and electricity distribution networks, in addition to destroying over a million buildings and causing over 19,500 deaths unrelated to the nuclear facility. This destruction highlights an issue noted in the section above; critical infrastructure may be unreliable in the event of a nuclear incident, because the event (likely a natural disaster or terrorist attack) which causes a severe nuclear incident may also damage local infrastructure.

Sovopol & Valentine estimate the total cost of the Fukushima nuclear incident to be $162 billion and list 21 deaths resulting from the incident. As we stress above, this cost estimate does not appear to be an economic cost, and it is also unclear how the authors arrive at 21 deaths. As of 2018, 50 Fukushima workers had been injured in the accident, but only one had died of radiation exposure according to the Japanese government. However, the Japanese government also officially lists 573 Fukushima deaths related to the evacuation and stress-induced factors. Outside estimates suggest the actual Fukushima Daiichi related death toll to be in the range of 1000-1600. This discrepancy in estimated deaths comes from the difficulty in attributing deaths to the incident at the nuclear facility vs. the earthquake itself, or to random chance. Applying a VSL of $9 million would suggest valuing these deaths at $9-14.4 billion.

The Tokyo Electric Power Company (TEPCO) estimates that the site will take 30-40 years to fully clean the site, at incredible expense. The Japanese government estimates that cleanup will cost $75.7 billion, an estimate that has been revised upward a number of times since 2011. Estimates from the Japan Center for Economic Research JCER (a private organization) for cleanup range as high as $660 billion. The total cost of the Fukushima incident could potentially approach $1 trillion, if pessimistic cost projections are correct.

The damage from Fukushima is not limited to the direct damage from the disaster itself. The lost electricity generation from Fukushima was replaced by more expensive fossil fuel generators. This issue was worsened when the Japanese government shuttered Japan's remaining nuclear facilities, shifting a tremendous amount of electricity generation onto fossil fuels. Neidell et al. find that this shift raised electricity prices by as much as 38% in some regions, causing consumers to ration electricity.

This resulted in increased deaths from exposure during colder months, resulting in an estimated 1280 deaths between 2011-2014, possibly outweighing the number of deaths from the incident itself. Shifting to fossil fuels has also increased CO2 emissions, contributing to climate change and causing economic damage. For a deeper discussion of pollution. Although Japan has made efforts to increase investment in renewable energy, it has also committed to building 22 new coal plants. Burning fossil fuels also results in emissions of particulate matter and other toxic gasses such as Sulfur Dioxide (SO2), which cause lung illnesses and have been shown to significantly increase mortality in exposed populations. The shift toward fossil fuels has therefore likely resulted in even more mortality increase than we document.

Evidence suggests that the Fukushima accident also decreased housing prices local to the accident site. Alistair (2018) finds that a 1% increase in 2011 radiation levels is associated with a .05% decrease in home price, and that this price decline persisted even after radiation levels declined. The Fukushima disaster appears to have lowered housing prices not just in the vicinity of the Fukushima accident, but in the vicinity of nuclear power plants worldwide by up to 5%. The size of these declines is difficult to justify given the historic risk of nuclear accidents, implying that the Fukushima disaster either significantly raised consumers' assessments of the risk of a nuclear accident, or that consumers only became aware of existing risk after the publicity surrounding Fukushima. There are several reasons to believe that home buyers response to Fukushima is rational. First, the decrease in housing prices in the vicinity of Fukushima seems driven by differentials in observed radiation levels on different properties, rather than distance to the accident site (Fumihiro et al 2013). This implies that home buyers in Japan are assessing the risk of radiation exposure using all available information, rather than making decisions based on rough heuristics such as distance to the accident site. Second, the effects on housing markets outside of Japan, specifically in the U.S., appear to have been short-lived and extremely local to nuclear power plants, with the effect only significant within four km of a nuclear power plant, and diminishing after about 6 months (Shinsuke & Zabel 2018). In addition, evidence from Germany suggests that the damage to housing markets from closing a local nuclear facility was roughly double the effect of decrease in prices caused by the increased assessment/salience of nuclear risks (Thomas et al 2017), meaning that an active nuclear plant nearby is beneficial to housing prices, even after Fukushima.

2.4 Germany Post-Fukushima

Post-Fukushima, an estimated quarter million German citizens protested in the street for an end to nuclear power in Germany. In response to this pressure, the German government agrees to phase out nuclear power in Germany between 2011-2017. Although there was much political pressure to close nuclear plants in Germany before Fukushima, and it cannot be said that Fukushima was the only contributor to the shuttering of nuclear generation in Germany, the Fukushima accident was an unexpected shock which resulted in a wave of political pressure, culminating in the closure of much of Germany's nuclear generating fleet in a short time period. The lost nuclear generation was ironically partially replaced by imported nuclear power from France, but the bulk of lost nuclear generation was replaced by domestic coal production. Jarvis et al. estimate that shifting from nuclear to coal cost Germany $12 billion dollars per year, $8.7 billion of which is caused by excess mortality related to coal pollution, using a VSL estimate of $7.9 million per life. This amounts to 1100 excess deaths per year from the closure of Germany's nuclear plants, a Fukushima sized disaster every single year. The remaining $3.3 billion in annual cost comes from climate damages and increased electricity prices. The German example leads us to conclude that the increase in coal usage in Japan has also resulted in increased mortality, although we lack the data to put this damage in numbers. The German case also highlights that the social and political response to a nuclear incident will not necessarily be separable from the incident itself in a cost analysis. In an interesting twist, policy makers planning for potential nuclear incidents may need to account for imperfect post-incident policy responses.

2.5 San Onofre Nuclear Generating Station (SONGS)

On January 31st, 2012, operators at the San Onofre Nuclear Generating Station in Southern California detected a leak inside one of the plant's steam generators, and the reactor was immediately shut down. Subsequent inspections revealed premature wear to critical components, resulting in a permanent shutdown of SONGS. Nuclear power plants are large, often with the capacity to generate over 2000 MW of electricity. SONGS had a capacity of 2150 MW, enough to have met up to 20% of southern California's total electricity demand by itself. Shutting down SONGS, or shutting down any other nuclear power plant, therefore places a large burden on substitute electricity generation sources. Additionally, although the up-front fixed cost of building nuclear power plants is high, the marginal cost of operating existing reactors is lower than the marginal cost of operating fossil fuel generators, meaning that shutting down nuclear facilities will shift a significant generation burden onto more expensive generators, raising electricity prices. Nuclear generation also generates no toxic air pollutants such as carbon dioxide, sulfur dioxide, or particulate matter, making nuclear far cheaper in terms of external pollution costs.

Because the shutdown of SONGS was sudden and permanent, this event provides an ideal natural experiment to test the effects of shutting down a nuclear facility on electricity markets. This is not to say that there were no contributing factors to SONGS closure aside from unexpected maintenance issues. SONGS was plagued by high operations and maintenance costs and policy controversy, which contributed to its closure. Rather, the unexpected nature of the closure provides evidence of how electricity markets would react to a nuclear plant closure without time to prepare for the closure, as might happen in the case of a natural disaster or terrorist attack.

This is exactly the analysis performed in Davis & Hausman (2016), who test the effect of the SONGS shutdown on electricity prices and carbon emissions in the California electricity market. The authors find that generation from SONGS was replaced almost entirely by natural gas generators, increasing wholesale electricity prices by $350 million dollars per year and resulting in an additional 9.02 million short tons of C02 emissions. SONGS fixed annual operations and maintenance costs were estimated to be $340 million, almost entirely negating the electricity price increase. However, the authors note that natural gas prices were historically low when SONGS closed. Had natural gas prices instead been at 2007 levels, then the wholesale price increase would have been twice as high.

Priced at $42 per ton, the additional CO2 emissions result in $379 million per year in social costs. Health costs from other pollutants such as sulfur dioxide and particulate matter are not included in this analysis, but Machol & Rizk (2013) estimate that natural gas generation results in health costs of $1-2 per MWh, meaning that SONGS closure likely resulted in an additional $16-32 million dollars per year in local health costs. It is worth noting that because the SONGS closure was permanent, these costs will also be permanent, up until renewable generation and/or battery storage technologies are able to replace lost nuclear generation at low cost and without additional carbon emissions. In total, estimated annual electricity market related damages from SONGS closure, net of operations and maintenance cost savings, are around $400 million dollars.

The results in Davis & Hausman are sensitive not only to swings in natural gas prices, but to the substitute generation mix within the electricity market. In California, lost nuclear generation from SONGS was replaced by natural gas generation, but it is easy to imagine a situation in which lost nuclear generation was instead replaced by coal. This occurred post-Fukushima in both Japan and Germany, when nuclear plants were shut down in favor of increased coal generation. Coal generation produces about twice as much C02 than natural gas generation on average, in addition to large increases in particulate matter, mercury, methane, S02, and N0x emissions above what natural gas produces. So what if the SONGS closure had instead shifted electricity generation burden towards coal rather than natural gas? First, the estimated environmental damage from CO2 emissions would roughly double to $768 million per year. Secondly, additional pollution damage from particulate matter, mercury, S02, and N0x emissions, which cause increased rates of lung disease, would need to be accounted for. Machol & Rizk (2013) estimate that coal generation causes $19-45 per MWh in health costs, resulting in between $304-720 million per year in total local health costs, had SONGS generation been replaced by coal rather than natural gas. Total electricity market costs in this scenario are $700-1000 million dollars annually, depending on the true health costs associated with coal power.

Of course, had lost generation from SONGS been replaced by out-of-state imported nuclear power, or by local renewables, then the increase in electricity and pollution costs would not have occurred. This outcome is unlikely do to the nature of electricity dispatch. Electric system operators dispatch the cheapest generators first to meet consumer demand, and dispatch increasingly expensive plants when electricity demand increases. When a generator, such as a nuclear power plant, goes offline for any reason, the gap in electricity supply will typically be filled by a more expensive generator. Renewables generally have near zero marginal generation costs, and are thus dispatched first by system operators. It is therefore likely that if enough spare renewable capacity were available to make up for shutting down a nuclear power plant, that the economic viability of the nuclear plant would have already been undermined, and the nuclear plant already shut down. The complementarity of nuclear and renewable power is a topic of ongoing study, and is outside the scope of this work, other than to note that renewables are unlikely to be a short run substitute for nuclear power.

2.5a Analyzing a Potential Accident or Attack on SONGS

SONGS shut down in January 2012 for safety reasons before any actual accident occurred. It is a useful exercise to consider a scenario in which SONGS was taken offline due to an accident, similar to Fukushima, or by a potential terrorist attack. A Fukushima style accident at SONGS is uncomfortably plausible. SONGS lies on the San Andreas fault line, and according to SONGS officials, the plant could withstand a 7.0 magnitude earthquake, but not necessarily a 9.0 magnitude earthquake like the one that struck Fukushima. In 2012, the NRDC performed an analysis mapping the fallout of a Fukushima-style accident at each of the 104 operating nuclear reactors in the United States. A map of potential fallout around SONGS is below:

The small circle represents the 10 mile evacuation zone around SONGS, while the larger blue circle represents the 50 mile evacuation zone. There are 126,000 residents within the 10 mile evacuation zone, and over 8 million residents within the 50 mile evacuation zone, according to the 2010 census. All these residents could potentially be affected by fallout from an incident which releases radioactive material into the atmosphere. The concentric red-to-yellow enclosures represent the severity of fallout from a Fukushima style accident. The innermost red enclosure is the area within which residents would be in danger of radiation sickness, while the outermost yellow enclosure is the area in which sheltering in place would be recommended. The 2200 employees at SONGS would likely have been in the most danger given an accident or attack.

It is reasonable to assume that the damage from a Fukushima style incident at SONGS could result in Fukushima level damages in the hundreds of billions of dollars especially if fallout from the accident were to reach densely populated areas in nearby Los Angeles or San Diego. Accidents worse than Fukushima must also be considered. The Chernobyl accident, for example, resulted in the establishment of a 30km exclusion zone around the reactor site almost entirely devoid of human activity. Were the same exclusion zone enacted after a hypothetical incident at SONGS, then, the entire nearby town of San Clemente would be rendered uninhabitable, resulting in a total loss for all local land values. GDP measures are not available at the city level, but there are about 24,000 households in San Clemente, and the median owner-occupied home value is $905,000 according to the US Census Bureau. If the area were abandoned, these homes would be a total loss, and back of the envelope calculations estimate this value to be almost $22 billion. San Clemente lies within Orange County, CA, which has an annual GDP per capita of $73,785. Suppose exclusion zones a la Chernobyl were enacted at the 10 or 50 mile radius around SONGS. Then, assuming a 5% interest rate, the net present value of affected GDP within a ten mile radius is $186 billion, and the net present value of affected GDP within a 50 mile radius is $11.8 trillion. We do not argue that such damages are likely, but merely wish to establish the magnitude of possible costs.

2.5.b Lessons from the SONGS Closure

The SONGS closure shows that closing nuclear plants can significantly increase electricity prices, and will result in hundreds of millions of dollars per year in annual costs due to increased pollution. The effect on electricity prices will depend critically on the price of substitute fuels such as coal or natural gas. The cost of pollution will depend on mix of substitute fuels – almost certainly coal and natural gas. While burning natural gas emits a significant amount of C02, burning coal results in twice as much C02 emission as natural gas per MWh of electricity generated. In addition, burning coal emits far more of other pollutants such as particulate matter, which cause orders of magnitude higher health costs per MWh than burning natural gas. Analysis of electricity market related costs of nuclear accidents will therefore depend on the mix of fuels which will replace a disabled nuclear reactor. SONGS also demonstrates how the costs of an accident or attack are dependent on nearby population density, as SONGS lies between highly populated San Diego and Los Angeles.

3. Political Costs & Consequences

There are many potential political costs consequences from an attack or accident at a nuclear facility that should be considered when assessing consequences, which cannot be included in economic modeling. Political consequences can be categorized into two main types – 1) political decision making about responses to incidents and 2) public opinion and political costs for governments.

3.1 Political Decision Making - Responses to Incidents

The first type of political consequence is related to the political nature of funding security and safety of nuclear facilities. These include: a) immediate compensation and costs of incidents at nuclear facilities that involve displacement, reimbursement, and healthcare, and b) the need for increased spending on more effective security and safety mechanisms at nuclear facilities.

3.1.a Political Aspects of Compensation and Costs

The first consequence involves the politicized decision making about how to respond to a nuclear incident and how to fund such responses. As discussed above, the economic costs can include compensation for displaced people, either temporarily or permanently, reimbursement for business that are temporarily or permanently closed in the vicinity of effected nuclear facilities, and healthcare costs for those exposed to radiation. All of these responses involve political decisions about how to implement such responses (moving people too late, too far, too many people or the opposite), how much government funding should be spent in response to the incident, and how the funds should be dispersed and to whom. After a nuclear incident, governments must tackle a dual strategy – how to collect and disseminate information in terms of assessment about the incident, and how to mitigate, control, and manage the incident and future risks.[2] Both of these phases involve political decision making and potential backlash from domestic and international audiences. The quality of the political leadership – whether a top-down or more lateral approach, or micromanaging versus guidance at the top level - matters significantly in this regard, as demonstrated by the enormous responsibility placed on leaders and the substantial media attention. Similarly, the quality of the political institutions surrounding a leader can be quite influential on the effectiveness of the response to a nuclear incident, particularly in regard to lines of communication, decision making, command and control, and crisis management. Levels of trust of bureaucratic institutions will directly affect the ability of these institutions to effectively handle nuclear related crises. This issue was demonstrated by Japanese Prime Minister Naoto Kan's poor relationship with the Japanese bureaucracy and failure to effectively respond to the Fukushima crisis.[3]

As with all government budgetary issues, debate and differing views can affect the decisions about such spending, yet in a crisis, the tensions run higher and decisions must be made in a much shorter period of time than is typical for other budgetary spending. Another political cost could result from the closure of a nuclear power plant and shift to another source of energy. If such a shift leads to increased energy costs, these costs could be dissatisfactory for the public, who could engage in protests or riots targeted at the government. For example, after micro-cracks were found in the Tihange nuclear power plant, a massive 50,000 human chain protest took place in Belgium, stretching into the Netherlands and Germany as well. The protestors demanded the shutdown of Tihange and Doel, where in addition to discovered micro-cracks, insider sabotage had also occurred, shutting down the plant for five months in 2014. Together with pressure by the governing coalition's Green Party, negative public opinion has strongly influenced the Belgian government's decision to completely phase out all nuclear power in the country by 2025.

3.1.b Political Aspects of Increased Security

The other politicized consequence regarding responses involves immediate clean up and repair costs as well as potential increased costs of building facilities that include more effective security and safety designs and technology that must be included not only to prevent further incidents, but also to address political concerns. Depending on the proximity to a nuclear accident, governments generally need to consider appeasing and assuring an affected population, which means that costs such as medical and mental health services and evacuation needs resulting from a nuclear incident will be higher.[4] The cost of future security mechanisms can be directly linked to domestic audience costs discussed below, depending on the regime type and domestic conditions. As with immediate responses to incidents, governments must consider how much to spend on increased safety and security, weighing the demands of the public and the requests of the facility managers with government spending capabilities and government interests. Increased spending on security and safety at nuclear plants can cost so much that other energy options become more attractive.[5] Such decisions can depend on the relationship between plant operators and the government, and how much the government chooses to regulate and provide oversight of private actors (such as TEPCO in Japan) involved in safety and security of nuclear facilities.[6] In circumstances with tight relations, lack of government regulatory oversight in which there could be cover-ups and lack of transparency, public trust in both nuclear industry and the government overall will be negatively affected.

3.2 Public Support for Government Policies

The second type of political consequences is "domestic audience costs," which refer to declining public support for the government in response to incidents directly, and government policies about nuclear technology and risk. These consequences include: a) decreased confidence and trust in governments to handle incidents and b) decreased public support for nuclear energy due to risk, including opposition to new construction of facilities, and presence of nuclear materials in a region or the country.

3.2.a Confidence and Trust in Government

A major consequence of nuclear incidents is the political cost to governments at the local, regional, or national levels. In liberal democracies, domestic accountability exists on a wide range of policy issues including nuclear energy, leading to strong rebuking, reduced trust in government, or even removal from office for government officials including the leader. After the 2011 disaster, the political costs were significant for the government of Japan due to the public perception of the government mishandling the incident. In the months after the incident, 58% of Japanese viewed the government as mishandling the response and recovery efforts and opposition parties were unwilling to join a coalition with the ruling party for fear of having some blame passed to them. Prime Minister Naoto Kan was “fighting for his political life,” also because he accepted foreign donations in breach of Japanese laws.[7] If public opinion of leaders and political parties is already low due to economic challenges, unemployment, and other social concerns, adding a nuclear incident crisis on top will only escalate government distrust and support.

3.2.b Anti-Nuclear Social Movements

A major effect of public opinion political and social cost that could occur as a result of a nuclear incident is the emergence and/or spread of anti-nuclear social movements that challenge the government’s use of nuclear facilities for energy, research, or weapons. In democracies, governments of countries like the United Kingdom acknowledge the “critical role of public acceptability” of energy options, ensuring that governments “must remain sensitive to the beliefs and preferences of the electorate” regarding nuclear issues.[8] There is clear evidence indicating that nuclear incidents are directly correlated to public opinion about nuclear facilities including waste disposal. After the Three Mile Island accident in the United States, opposition to nuclear power increased from 20% to 60%, while the Chernoybl accident similarly affected European views.[9] In Japan, even before the Fukushima incident, due to a series of minor nuclear accidents in the 1990s, public opinion was leaning toward opposition of expansion of nuclear power.[10] For example, after the 1999 Tokaimura reactor accident, the percentage of Japanese who felt “very uneasy” about the risk of nuclear accidents increased from 25% to 52%, resulting in a cancelled or delayed development of nuclear facilities.[11] Even after only three reactors were restarted after stricter nuclear regulatory standards were set up, citizens groups legally challenged one of the reactors, which was shut down as a result. Such public opinion affects confidence in government, which can affect policy decisions about growth of nuclear programs. Together with lack of transparency, secrecy, and limited information, nuclear incidents have strong negative effects on levels of trust among the public.[12] In countries where accidents have not occurred, there can be severe resistance among society and strong public views about nuclear power and the presence of nuclear material in particular countries. Public perceptions of hazardous technologies like nuclear energy depend on the balance between risk and benefits of nuclear energy.[13]

Potential incidents will undoubtedly affect public opinion about nuclear sources in their country, but this could be dependent on public awareness of the risks of nuclear facilities. In countries like China where governments have effectively minimized and subordinated public opposition to nuclear programs, pro-nuclear governments are better able to develop nuclear programs without contentions from the public.[14] These efforts at government subordination are more feasible in authoritarian regimes, as well as countries with dominant ruling parties like Japan and India, or places where the media can be controlled or highly influenced by government suggestions. In democracies, the media and opposition groups in particular can have significant influence over government decision making regarding nuclear issues, [15]as well as pro-industry lobbying groups that can be highly influential on government decision making regarding nuclear policy and individual leaders who advocates of nuclear energy.[16]

Additionally, after such incidents, there will likely be significant policy discussions about the use of nuclear energy in particular, and whether such facilities are worthy of further investment by governments. After the Fukushima accident, 74% of the Japanese public preferred ending nuclear energy in Japan.[17] This was demonstrated broadly in anti-nuclear protests, which together with public opinion, put significant pressure on the Japanese government to reconsider the future of nuclear power in Japan. Even 10 years after the incident, 70% of Japanese support the reduction or complete abolition of nuclear power.[18] Not only does the government have to consider public opinion on nuclear power, but national level governments may also need to negotiate with local and regional governments to acquire approvals for plant locations and operations, and records of regulation, security, and safety will play a key role in local and regional government decisions. Such approvals are particularly important since opposition to the construction of new nuclear facilities is common in the communities nearby.[19] Nuclear coalitions – for or against – can influence the narrative of "risk politics" surrounding the use of nuclear energy in particular after a nuclear incident like the Fukushima shutdown.[20] On the other hand, strong lobbying by power utilities and corporations involved in nuclear power can have significant influence in countering anti-nuclear efforts,[21] causing governments to balance the demands of industry against public pressure.

4. Policy Implications & Key Takeaways

Although nuclear incidents are rare, they are often quite expensive and potentially deadly. In addition, nuclear power carries with it the risk of catastrophic accidents if proper precautions are not followed, and in the event of extreme natural disasters. These findings lead to several clear takeaways. There are several policy implications that governments can consider based on the above assessment of economic and political costs and consequences that can result from attacks or accidents at nuclear facilities.

First, given the extraordinary potential cost of severe nuclear incidents, reducing the probability of a severe incident even slightly, or mitigating even a small proportion of the damages from severe incidents, can yield large expected cost savings. Decreasing the probability of a trillion-dollar incident by .0001% will yield an expected savings of $1 million, so policy interventions which cost millions of dollars can be justified on a cost-benefit analysis basis if they decrease the likelihood of worst-case scenario accidents or attacks by even a tiny amount. Health related damages, and specifically deaths, tend to make up a large portion of the estimated costs of severe incidents. Therefore, planning which mitigates deaths from an incident may be most cost-effective.

Second, social and policy response by consumers, businesses, or government officials may expand the scope of economic damage outside of the immediate area of a nuclear incident. For example, the German government's decision to close down domestic nuclear generation after Fukushima caused considerable harm to the German economy in the form of increased use of coal for electricity generation. Consumers worldwide also seemed to increase their risk assessment of nuclear power after Fukushima, as evidenced by increasing home prices near nuclear facilities worldwide which never had a safety incident, and the declining reputation of nuclear power in opinion surveys.

Third, governments, and specifically leaders, can consider themselves to be advocates for nuclear energy. Influential politicians can play a key role in persuading the public about nuclear safety and security. This involves building social trust with the public, reassuring the public that nuclear facilities are secure and safe and risks of attacks or accidents are low. Public awareness of nuclear issues, the importance of public opinion and the potential for domestic audience costs, and the role of NGOs are all factors that can influence the importance of governments building social trust of nuclear facilities in the country. Public opinion surveys clearly indicate that public views toward nuclear issues matter for governments and it would be potential unwise for governments to ignore such views. Governments should be prepared for responses to potential nuclear incidents and the likely negative responses to both the government and the future of nuclear power.

Fourth, clear communication about risk and crises that result from nuclear attacks or accidents could be prioritized by working with citizen science networks and civil society groups that can help the government to use language understood by the public.[22] To avoid panic or distrust of the government during and after a nuclear crisis, governments can work to provide scientific information and work with the media and others to prevent disinformation. Communication strategies work best when they are transparent, detailed, immediate and in terms understood by the media and the public. Involving members of the public as citizen scientists can help to build government credibility and trust.

Fifth, to respond effectively to nuclear incidents, whether deliberate or accidental, governments may consider involvement of independent experts to assist with information, transparency, and response. Effective relationships between government officials and nuclear facility operators should not be too close, as in the case of Japan, where a culture of potential conflicting interests and lack of transparency and accountability has occurred.

Overall, the economic and political costs and consequences of incidents – whether deliberate attacks or due to natural disasters of accidents – can be quite high. Governments that control nuclear facilities must be fully prepared to prevent threats and accidents in order to protect economy, stability of their own government, and other costs to society, including the prevention of social disorder and mental and physical health effects of their citizens. The potential costs and consequences provide significant justification for why high levels of nuclear security and potential incident training is necessary and why it is important for governments to avoid taking shortcuts with nuclear facilities.

Notes

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