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Public Exposure to U.S. Commercial Nuclear Power Plants Induced Disasters

Dean Kyne[1]

Abstract   This study explores the potential risks associated with the 65 U.S.-based commercial nuclear power plants and the distribution of those risks among the populations of both their respective host communities and of the communities located in outlying areas. First, it starts by examining the racial/ethnic composition of the host community populations, as well as the disparities in socioeconomic status that exist, if any, between the host communities and communities located in outlying areas. Second, it utilizes two independent-sample T tests to identify any differences in the sociodemographic compositions of the two areas. Third, it explores regional demographic trends by looking at the percent change in demographic variables in the host communities and communities located in outlying areas in 1990–2000 and 2000–2010. Findings reveal that during the past two decades more people were exposed to the risks as population living in the host communities increased.

Keywords   Exposure to nuclear power disasters · Host communities · Nuclear disasters · U.S. commercial nuclear power plants

1 Introduction

The most recent catastrophic nuclear event, which occurred at Japan's Fukushima Daiichi nuclear power plants (NPP) in March 2011, served to remind us of the unpredictable and extreme risks associated with nuclear power. Other notable NPP accidents include Three Mile Island in the United States in 1979 and Chernobyl in Soviet Ukraine in 1986. The inescapable risk associated with a NPP is substantially amplified when that risk is coupled with any geological or other natural hazards, such as an earthquake, tsunami, flood, or other catastrophic event. On 11 March 2011, a massive earthquake registering a 9.0 magnitude triggered a tsunami that washed up on the coast of Miyagi Prefecture, Japan, where the Fukushima NPP is sited. The earthquake caused a blackout, which brought down the cooling system for the reactors' nuclear fuel rods. The collapse of cooling resulted in the release of radioactive materials into the environment (Baba 2013). The Fukushima NPP was not designed to withstand such a tsunami, despite having been sited near the coast in a tectonically active zone (Acton and Hibbs 2012). Designed to accommodate a tsunami-driven surge estimated to be at most 3.1 m above sea level, the seawater intake was built at 4 m above sea level. The building was built 10 m tall, on a cliff that rises 25 m above the shoreline. During the event, the seawater pumps were inundated when a 14 m high wave washed over the coastline. According to Kan (2013), cost savings was the underlying motive behind the decision of Tokyo Electric Power Company (TEPC) to go forward with such a low projected height for a tsunami-driven surge in its design and construction of the Fukushima NPP. In the long-run, the pay-off from the cost savings came with a price tag far beyond anything one could possibly have imagined.

The immediate threat from any NPP-related disaster comes in the form of ionizing radiation emitted from the core, where the nuclear fuel rods are housed. As part of their normal, day-to-day operations, NPPs emit low levels of ionizing radiation that may pose health risks to those

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living in proximity and subject to prolonged exposure (Blevins and Andersen 2011). In general, the ionizing radiation emitted from NPPs has been linked to various forms of cancer, permanent damage to human vital organs, and death (Astakhova et al. 1998; Cardis et al. 2005; Canu et al. 2008; Anzai et al. 2012). The Fukushima NPP began to release significant excess radiation into the atmosphere the day after the accident (Thakur et al. 2013; Baba 2013).

In the event of a nuclear disaster, ionizing radiation can quickly travel over great distances as the wind carries a radioactive-effluent plume over outlying areas (Cyranoski and Brumfiel 2011). In the aftermath of the event at Fukushima, such radioactive effluents were released in two forms—gaseous and liquid. These effluents included isotopes of noble gases such as xenon (^{133}Xe), krypton (^{85}Kr), iodine (^{131}I, ^{132}I), cesium (^{134}Cs, ^{136}Cs, ^{137}Cs), and tellurium (^{132}Te). Due to the high levels of radiation released, the Fukushima accident ranked as a level-7 event according to the International Nuclear Event Scale (INES), where 1 is abnormal and 7 represents a major accident (Thakur et al. 2013). In addition, a large but unknown amount of highly contaminated water was discharged from the three reactors and eventually made its way into the ocean and groundwater (Baba 2013). The amount of water discharged into the ocean was and remains unknown, and TEPC has since informed the public that water that had leaked from one of the more than 1000 storage tanks at the site was found to have radiation levels sufficient to kill a person within 4 h of exposure (Lazare 2013). An estimated 80,703 gallons of contaminated groundwater continues to flow into the ocean daily (Yamaguchi 2013).

United States commercial NPPs are vulnerable to natural hazard events. When impacted by such a hazard, it is likely that many would prove unable to withstand the event (Cappiello and Donn 2011). Given the number of "near-miss" events recorded over the past 3 years, there would seem to be ample potential for an accident to occur that, with better preparation and strengthened safeguards in place, could have been avoided. The severity of any such accident and its negative impacts on the lives of the people living in the nearby communities would be difficult to overestimate. Evaluation tasks are immense and complex, and cleaning up radioactive contamination requires international experts, immense financial resources, and decades, if not centuries, as the Japanese case is illustrating all too clearly.

The communities that host NPPs inevitably bear the burden of the persistent risks associated with them. In instances in which the host communities were not allowed to participate in the decision-making process that resulted in a NPP being sited in their area, the communities have had to involuntarily bear the risk of negative environmental impacts deriving from the plant, thus raising a number of environmental justice issues.

In the early years of civilian nuclear power, between 1957 and 1975, the U.S. Atomic Energy Commission (AEC) oversaw the NPP siting process. The AEC was founded under the Atoms for Peace program, which was later transformed into the Price-Anderson Act of 1957 (Hochfelder 1999). Under the AEC's guidelines, appropriate site selection was based on Part 100 of Title 10 of the Code of Federal Regulations (CFR), which included three key criteria—exclusion area, low-population zone, and population center distance (Greenberg and Krueckeberg 1974). The AEC's decision making in the siting process saw it exposed to criticism for its having to play dual roles, as both promoter and regulator of nuclear energy (Golay et al. 1977), and for the vagueness of these three key terms (Greenberg and Krueckeberg 1974). Of course, the idea of environmental justice did not exist during the era of AEC administration, so one cannot expect their guidelines to have considered issues of social equity. During its administration, the AEC issued operating licenses for 126 reactors, of which 103 remained in operation, 22 had been shut down, and one was temporarily closed as of August 2012 (U.S. NRC 2012c).

In 1970, the New Environmental Policy Act (NEPA) went into effect and the Environmental Protection Agency (EPA) was established. Part of the EPA's mission was to incorporate environmental justice policy into all federally sponsored projects. In 1975, after take into consideration criticisms of the AEC, the U.S. Nuclear Regulatory Commission (NRC) was founded by the Energy Reorganization Act of 1974 (U.S. NRC 2011b). The NRC was given sole responsibility for the licensing of all nuclear power reactors in the country through a two-step licensing process, which included both a construction and an operating license application (U.S. NRC 2012c). By law, public participation in the licensing process was encouraged through adjudicatory (or courtroom-style) hearings that disclosed the proposed plant's conformity with existing environmental law and any quality of design and construction issues (Mariottee 2006). After 1992, the licensing process was reorganized into a single step. The new, simplified, one-step process has been the subject of some criticism, however, as it placed greater constraints on public participation and bestowed more advantages upon nuclear operators. Public participation was seen to be discouraged by the requirement of legitimate contentions for each public hearing by the Atomic Safety and Licensing Board (ASLB), a three-judge panel of NRC employees made up of two technical experts and one attorney. The time frame during which the public was able to file such contentions was limited to a 60-day window, and the high costs of attorney's fees and the fees needing to be paid to expert witnesses also acted to limit the public's ability to intervene in the licensing process (Mariottee 2006). These procedural limitations might have contributed to decisions made around environmental justice issues that have since

negatively impacted the health and wellbeing of people living near the power plants.

Environmental equity studies emerged out of the then-nascent environmental justice movement in the U.S. South in the early 1980s. The emergence of anti-NPP movements, however, preceded the environmental justice movement by more than 20 years, linked to preexisting antinuclear-weapons movements of the 1950s (Gottlieb 2005). Beginning in the 1960s, broad antinuclear technology movements began to contest the siting of NPPs at various locations in the United States over concerns of ionizing radiation and the plants' potential for nuclear accidents (Gottlieb 2005). Contested sites included: Calvert Cliffs Nuclear Power Plant, Maryland; Seabrook Station Nuclear Power Plant, New Hampshire; Diablo Canyon Power Plant, California; Shoreham Nuclear Power Plant, North Carolina; and Three Mile Island Nuclear Generating Station, Pennsylvania (Giugni 2004). With the cessation of construction of new NPPs in the United States as of the 1980s, the anti-NPP movement substantially slowed but nuclear power remained a potent local concern, especially in those communities that already hosted nuclear facilities (Gottlieb 2005).

While justice and equity were not part of the discourses of the previous antinuclear power campaigns, they do figure prominently in environmental justice studies. According to Bullard's definition (1996), environmental justice refers to the equal protection from environmental harms of all peoples, regardless of race, sex, income, and age. This definition emphasizes equity as essential to environmental justice. According to Margai (2010), environmental equity has a broader context and engages with the geographical and spatial distribution of environmental risks. For Bullard and colleagues, environmental equity can be distilled into three categories—namely, procedural, geographic, and social equity (Bullard et al. 2007). Procedural equity concerns fairness in environmental decision-making processes, which is often examined by looking into how and whether rules, regulations, and systematic evaluation criteria are applied in a uniform and nondiscriminatory way. Geographic equity investigates whether environmental risks are equally distributed according to the spatial location of communities and their proximity to potentially hazardous and/or toxic facilities. Social equity evaluates how sociological factors—such as race, ethnicity, class, culture, lifestyle, and political power—influence environmental decision making. With its focus on proximity-based assessment, the present study focuses on two types of equity—namely, geographic and social—in attempting to answer the research questions presented below.

With a primary goal of addressing environmental justice issues, President Clinton in 1994 signed Executive Order 12,898, which required each federal agency to have a plan "that identifies and addresses disproportionately high and adverse human health or environmental effects of its programs, policies, and activities," and to "make environmental justice a part of all they do" (Bowen et al. 1995, p. 641). The 65 NPPs currently operating in the United States, however, all were built between 1964 and 1978 (U.S. NRC 2011b), well before President Clinton's Executive Order was put into effect. That Executive Order now provides grounds for environmental justice assessments based on the current guidelines in place for the NPP siting process as defined by the NRC. The siting decisions of the U.S.-based NPPs currently in operation therefore were made in a period during which the inequitable impacts of industrial hazards simply were not considered in the procedures for the selecting of appropriate sites. Given the by now well-documented evidence that, in many cities, hazardous industries are disproportionately located in areas with predominantly poor and minority populations, the question that naturally follows is: Do NPPs exhibit similar patterns of inequitable proximity to low-income and racial minority populations?

The primary goal of this study is to investigate the potential environmental risks borne by the communities living in proximity to the 104 nuclear reactors at 65 NPPs currently operating in the United States. In particular, this study examines whether minorities and the poor are over-represented in host communities. Consistent with the emergency evacuation guidelines set forth by the NRC (U.S. NRC 2011a), this study considers two exposure zones that mirror the two emergency planning zones (EPZs) the NRC calls for to surround any NPP: the plume-exposure pathway EPZ, which is the area within a 10-mile radius of a NPP; and, the ingestion pathway EPZ, which is the area within a 50-mile radius. There is no publicly available historical data on different radiation dosage levels as sorted by distance from NPPs that could be used in order to estimate the extent of risk by distance. Therefore, the present study uses a proximity-based assessment of NPPs and measures equity in terms of the distribution of outcomes. Proximity-based assessment focuses on exposure to risk arising from the presence of a hazardous or toxic facility and makes no attempt to analyze the extent of the risk (Cutter et al. 1996; Bolin et al. 2002)—that is, the assumption is made that, all else being equal, living closer to a NPP is riskier than residing in a more distant location.

In order to achieve the primary goal to this study, the author sought an answer to the following question: Are the disparities in the sociodemographic characteristics of the populations of communities within a 50-mile radius of a NPP greater than the same disparities of populations living in communities that are outside of a 50-mile radius from a NPP?

2 Study Area and Data

The study area and types of data used in the study are discussed as follows.

2.1 Study Area

This study includes data from 104 U.S.-based commercial nuclear power reactors, distributed across 65 NPPs, as of January 2011 (Fig. 1) (U.S. NRC 2012a). Many are clustered along the U.S. eastern seaboard; in fact, there are only eight

reactors at four NPPs in the American West. One reason for this concentration might be that the U.S. East Coast has a greater demand for electricity consumption due to its denser population; another might be that the West coast is far more tectonically active, with some areas up to 100 times more likely to experience an earthquake than any place on the East
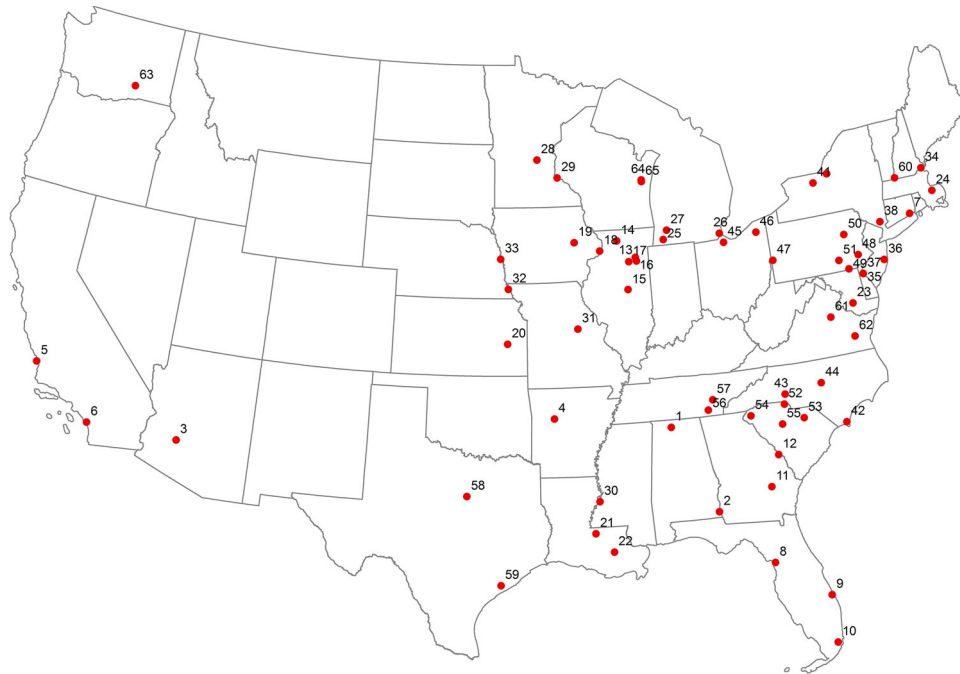
Index	Nuclear Power Plant, State	Index	Nuclear Power Plant, State
1	Browns Ferry, Alabama	34	Seabrook, New Hampshire
2	Farley, Alabama	35	Hope Creek, New Jersey
3	Palo Verde, Arizona	36	Oyster Creek, New Jersey
4	Arkansas Nuclear, Arkansas	37	Salem, New Jersey
5	Diablo Canyon, California	38	Indian Point, New York
6	San Onofre, California	39	FitzPatrick, New York
7	Millstone, Connecticut	40	Nine Mile Point, New York
8	Crystal River, Florida	41	Ginna, New York
9	Saint Lucie, Florida	42	Brunswick, North Carolina
10	Turkey Point, Florida	43	McGuire, North Carolina
11	Hatch, Georgia	44	Shearon Harris, North Carolina
12	Vogtle, Georgia	45	Davis-Besse, Ohio
13	Braidwood, Illinois	46	Perry, Ohio
14	Byron, Illinois	47	Beaver Valley, Pennsylvania
15	Clinton, Illinois	48	Limerick, Pennsylvania
16	Dresden, Illinois	49	Peach Bottom, Pennsylvania
17	La Salle, Illinois	50	Susquehanna, Pennsylvania
18	Quad Cities, Illinois	51	Three Mile Island, Pennsylvania
19	Duane Arnold, Iowa	52	Catawba, South Carolina
20	Wolf Creek, Kansas	53	Robinson, South Carolina
21	River Bend, Louisiana	54	Oconee, South Carolina
22	Waterford, Louisiana	55	Summer, South Carolina
23	Calvert Cliffs, Maryland	56	Sequoyah, Tennessee
24	Pilgrim, Massachusetts	57	Watts Bar, Tennessee
25	D.C. Cook, Michigan	58	Comanche Peak, Texas
26	Fermi, Michigan	59	South Texas, Texas
27	Palisades, Michigan	60	Vermont Yankee, Vermont
28	Monticello, Minnesota	61	North Anna, Virginia
29	Prairie Island, Minnesota	62	Surry, Virginia
30	Grand Gulf, Mississippi	63	Columbia, Washington
31	Callaway, Missouri	64	Kewaunee, Wisconsin
32	Cooper, Nebraska	65	Point Beach, Wisconsin
33	Fort Calhoun, Nebraska		

Fig. 1 U.S. commercial NPPs in operation as of August 2012; decommissioned or otherwise inactive NPPs have been omitted. *Source* U.S. NRC (2012a)

coast. The NPPs sited on the East coast do not include in their designs technologies or design features meant to mitigate against strong earthquakes, and therefore cost less to build than would an otherwise similar NPP on the West Coast (Koch 2011).

This study includes two discrete study areas. One is those areas within a 50-mile radius of any one of the 65 U.S.-based NPPs (Fig. 1); the other is those areas outside of a 50-mile radius and yet that are located in the state(s) that fall within said 50-mile radius. This study excludes from its analysis 20 reactors that have been permanently deactivated. Among them, seven reactors are located at NPPs that otherwise remain active. These 20 reactors do not pose the same level of risk as do reactors currently in operation. Functioning reactors pose increased risks as a result of their day-to-day operation, the possibility of a core meltdown-type accident, and their potential release of gaseous and liquid radioactive effluents. Reactors may also represent a potential radiation risk as a result of any spent fuel that is stored on site. In order to ensure that this study compared apples to apples, spent fuel storage sites were not included.

2.2 Data

This study investigated the demographic characteristics of populations living in either of the two study areas described above. The demographic variables included both racial/ethnic and socioeconomic variables. The racial/ethnic variables included the categories White, Black, Asian, Hispanic, Native American, Other, and Color. They are defined as: (1) Percent White is percent of all non-Hispanic Whites; (2) Percent Black is percent of non-Hispanic Blacks or African Americans; (3) Percent Asian is percent of Asian, and Native Hawaiian or Other Pacific Islander; (4) Percent Native American is percent of American Indian or Alaska Native; (5) Percent Other is percent of some other race who are not included in the White, Black, or African American, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander race categories; and (6) Percent Color is percent of all other races except non-Hispanic Whites; and (7) Percent Hispanic is percent of people who are of Hispanic origin. The socioeconomic variables selected for inclusion were renter-occupied housing, unemployment rate, percent living in poverty, mean household income, and percent composition at the census-tract level.

In addition to the demographic variables here described, this study also included several other variables. To analyze any proximity-based disparities present in a given demographic variable, distance from a NPP was used, measured in Euclidean distance from the census-tract center point to the NPP in miles. The measurement was performed using ENVI's ArcMap program. This distance variable was used to examine whether and how disparities in certain demographic characteristics were associated with distance from a NPP.

To answer the research question, this study first secured access to multiple datasets. To investigate demography-based disparities in the study areas required three discrete datasets. First, for demographic characteristics, the author obtained data published by the U.S. Census Bureau and GeoLytics—namely (1) U.S. Census 1990, long form, normalized to 2010 census-tract boundaries (GeoLytics 2012b); (2) U.S. Census 2000, long form, normalized to 2010 census-tract boundaries (GeoLytics 2012a); and (3) U.S. Census 2010/American Community Survey, 5-year estimate (GeoLytics 2012c). The use of census tract boundaries normalized to those of 2010 for data collected as part of the 1990 and 2000 censuses was vital to this study, as it allowed comparison of census data from the 1990, 2000, and 2010 surveys. Since the data are only available at the census-tract level, this study takes a census tract as the base geographical unit of analysis. The datasets that result from each respective survey include racial and ethnic subgroups—namely, White-alone, Hispanic-alone, American Indian- or Alaskan Native-alone, Asian-alone, Black or African American-alone, Native Hawaiian or Other Pacific Islander-alone, and Other-alone—as well as one additional category, "Two or more races," that is included only in the 2010 dataset. In addition, other socioeconomic data—such as gender, age, income, poverty, employment status, education, housing situation (owner-occupied versus renter-occupied), and citizenship status (native-born versus naturalized)—were available from each survey.

Second, in order to regularize administrative boundaries for spatial analyses, the author downloaded the national-level shapefiles that join the geometry and certain select attributes from the 2010 Census TIGER/Line Shapefiles and the 2010 U.S. Census Summary File 1 Demographic Profile (DP1) for the United States and Puerto Rico from the United States Census Bureau's website (United States Census Bureau 2010).

Third, information including the location of each of the 104 nuclear reactors currently in operation in the United States was obtained from the NRC's website (U.S. NRC 2012b). The data include general information on the reactors—namely, reactor type and containment type, design type, docket number, licensee, operating license issue date, commercial operation start date, renewed operation license issue date, and operating license expiration date. The author acquired latitude and longitude information for individual NPPs using Google Earth; the XY coordinates thus obtained were then manually entered into a separate sheet.

3 Method

The center point-distance approach was used to measure the exact distance between census-tract center point and the NPP. First, the author determined the geographic center point of each included census tract in ArcMap 10.1. Next,

those geographic center points that fell within a 50-mile radius of the nearest NPP were identified using the "near" tool in ArcMap 10.1. This provided the exact distance between the census tracts' center points and the relevant NPP.

Descriptive statistics were computed for the sociodemographic characteristics of populations living within a 50-mile radius of one of the 65 NPPs currently in operation in the United States as well as for populations living in the outlying areas. The populations living within 50 miles of a NPP were then further subdivided into five categories, defined by distance: 0–10 miles from a NPP, 11–20 miles, 21–30 miles, 31–40 miles, and 41–50 miles; this was in addition to the broader category 0–50 miles. Using these six distance-based categories, this study examined the demography of the populations living at each distance and included nearby NPPs described as national, regional, urban, and individual. Statistical tests were conducted to investigate whether there were statistically significant differences in the demographic characteristics of populations living within a 50-mile radius as compared to those living in outlying areas. In doing so, this study utilized two independent-sample T tests to identify any differences in the sociodemographic compositions of the two areas. The T test analyses were conducted in STATA 12.

4 Findings

The discussion of the findings based on above mentioned research method is as follows.

4.1 Overall Demographic Composition by Distance

This section first presents the disparities that exist in certain sociodemographic characteristics, including racial, ethnic, and socioeconomic variables, between those communities within a 50-mile radius from a NPP (host communities) and those communities outside of a 50-mile radius, based on U.S. Census data for the years 1990, 2000, and 2010. It then describes the disparities in those same sociodemographic characteristics for communities that fall within one of the six distance categories—0–10 miles from the nearest NPP, 11–20 miles, 21–30 miles, 31–40 miles, 41–50 miles, 0–50 miles, and more than 50 miles from the nearest NPP, across the period spanning 1990–2010. Finally, the section discusses the overall sociodemographic characteristics of the populations living in NPP host communities and highlights the trends in these variables for the years 1990, 2000, and 2010.

As of 2010, a total of 96 million people lived within a 50-mile radius from the nearest NPP, whereas an estimated 208 million people lived in what are described as "outside areas" (Table 1), defined as areas that fall outside of a 50-mile radius from the nearest NPP. In other words, more than 3 persons out of every 10 (96 million out of 304 total U.S. population) lived within a 50-mile radius of a NPP according to the 2010 U.S. Census. Among the communities located within such a radius, 71.1 % of the population classified themselves as White, 16 % Black, 15 % Hispanic, and 5 % Asian, whereas among the communities located in outside areas, 75.1 % of the population classified themselves as White, 10 % Black, 16 % Hispanic, and 5 % Asian. In

Table 1 Demographic composition according to area, sorted by distance from any one of the 65 U.S.-based commercial NPPs, based on 2010 American Community Survey Data

Distance (miles)	0–10	11–20	21–30	31–40	41–50	0–50	Outside#
Tracts	908	3290	6204	7864	5129	23,395	49,662
Tract area (sq. miles)	18,258	54,900	81,180	94,216	52,248	300,801	3495,942
Total population	3,943,881	13,749,623	25,548,082	32,349,698	20,480,364	96,071,648	207,893,616
White	3,280,113	10,988,148	18,811,164	22,006,806	12,961,839	68,048,072	156,847,632
Black	408,088	1,593,169	4078,036	5595,517	3807,400	15,482,210	22,496,542
Asian	81,047	398,638	958,199	1849,310	1588,819	4876,013	9,801,153
Native American	11,233	41,975	77,305	125,688	76,503	332,704	2,147,761
Others	163,400	727,693	1623,379	2772,377	2045,804	7332,653	16,600,536
Hispanic	330,049	1440,563	3284,573	5287,229	3646,221	13,988,635	33,738,896
Color	880,263	3,661,789	8704,444	13,187,954	9366,389	35,800,840	71,591,664
White (%)	83.17	79.92	73.63	68.03	63.29	70.83	75.45
Black (%)	10.35	11.59	15.96	17.30	18.59	16.12	10.82
Asian (%)	2.06	2.90	3.75	5.72	7.76	5.08	4.71
Native American (%)	0.28	0.31	0.30	0.39	0.37	0.35	1.03
Others (%)	4.14	5.29	6.35	8.57	9.99	7.63	7.99
Hispanic (%)	8.37	10.48	12.86	16.34	17.80	14.56	16.23
Color (%)	22.32	26.63	34.07	40.77	45.73	37.26	34.44
Renter housing units (%)	22.17	25.66	28.78	33.05	34.54	30.69	28.73

Table 1 continued

Distance (miles)	0–10	11–20	21–30	31–40	41–50	0–50	Outside#
College degree or higher (%)	28.11	30.22	29.97	30.27	29.98	30.03	26.90
Unemployed (%)	7.21	7.35	7.99	8.47	8.29	8.09	7.84
Poverty (%)	10.09	11.23	12.78	13.53	13.28	12.81	14.28
Mean household income ($)	75,090	76,928	74,927	75,865	76,387	75,845	68,593

Distance was measured between census-tract centroid points and NPP in miles. The category "Outside#" includes all areas within the U.S. that do not fall within a 50-mile radius of any one of the 65 U.S.-based NPPs. Mean household income is real dollar value as of 2010

Data Source GeoLytics (2012c)

Table 2 Demographic composition according to area, sorted by distance from any one of the 65 U.S.-based commercial NPPs, based on 2000 American Community Survey Data normalized to 2010 U.S. Census boundaries

Distance (miles)	0–10	11–20	21–30	31–40	41–50	0–50	Outside#
Tracts	908	3290	6204	7864	5129	23,395	49,662
Tract area (sq. miles)	18,258	54,900	81,180	94,216	52,248	300,801	3,495,942
Total population	3,462,639	12,549,504	24,021,128	31,031,720	19,531,042	90,596,032	190,825,872
White	2,967,500	10,340,303	18,184,338	21,605,748	12,720,314	65,818,204	145,535,520
Black	322,478	1363,193	3767,229	5317,959	3662,384	14,433,243	19,928,496
Asian	46,067	257,474	628,868	1371,079	1145,248	3448,736	7,101,866
Native American	11,325	43,803	82,672	137,983	80,343	356,126	2,091,863
Others	115,385	544,534	1358,065	2598,859	1922,802	6539,645	16,168,205
Hispanic	182,469	926,000	2343,231	4081,065	2830,356	10,363,121	24,875,360
Color	599,702	2738,645	7135,217	11,300,120	8057,747	29,831,432	57,076,336
White (%)	85.70	82.40	75.70	69.62	65.13	72.65	76.27
Black (%)	9.31	10.86	15.68	17.14	18.75	15.93	10.44
Asian (%)	1.33	2.05	2.62	4.42	5.86	3.81	3.72
Native American (%)	0.33	0.35	0.34	0.44	0.41	0.39	1.10
Others (%)	3.33	4.34	5.65	8.37	9.84	7.22	8.47
Hispanic (%)	5.27	7.38	9.75	13.15	14.49	11.44	13.04
Color (%)	17.32	21.82	29.70	36.41	41.26	32.93	29.91
Renter housing units (%)	23.22	26.62	30.41	35.18	36.99	32.61	29.92
College degree or higher (%)	23.93	26.36	26.02	26.28	25.66	26.00	23.63
Unemployed (%)	4.76	4.84	5.67	5.97	6.33	5.76	5.78
Poverty (%)	8.89	9.36	11.44	12.30	12.79	11.64	12.73
Mean household income ($)	73,790	76,448	74,420	75,114	75,252	75,095	68,422

Distance was measured between census-tract centroid points and NPP in miles. The category "Outside#" includes all areas within the U.S. that do not fall within a 50-mile radius of any one of the 65 U.S.-based NPPs. Mean household income is real dollar value as of 2010

Data Source GeoLytics (2012b)

addition, the category "Color"—a container category that includes the total population excluding non-Hispanic Whites—was more prevalent among communities within a 50-mile radius of a NPP (37 %) than among communities in outside areas (34 %). In 2010, the overall U.S. population was 74.0 % White, 13 % Black, 16 % Hispanic, and 5 % Asian (and so, 34 % Color). Communities within a 50-mile radius of a NPP include fewer non-Hispanic White people as compared to communities in outside areas, and therefore those communities near to a NPP include a greater percent of people of other races and ethnic groups—namely, Black,

Asian, and Hispanic—as compared to communities in outside areas. In comparison to those living in communities within a 50-mile radius of a NPP, the population of communities located in outside areas are poorer (they earn lower than the average household income); are less likely to live in renter-occupied housing units; are less likely to hold a college degree or higher; and are more likely to be employed. There are no notable differences in either age or gender between the two areas. I identified similar patterns for the sociodemographic characteristics of the communities for the years 2000 (Table 2) and 1990 (Table 3).

Table 3 Demographic composition of according to area, sorted by distance from any one of the 65 U.S.-based commercial NPPs, based on 1990 American Community Survey Data normalized to 2010 U.S. Census boundaries

Distance (miles)	0–10	11–20	21–30	31–40	41–50	0–50	Outside#
Tracts	908	3290	6204	7864	5129	23,395	49,662
Tract area (sq. miles)	18,258	54,900	81,180	94,216	52,248	300,801	3,495,942
Total population	3,000,656	10,993,087	21,902,998	28,411,958	17,765,938	82,074,640	166,634,720
White	2,660,292	9,521,418	17,634,048	21,626,328	12,821,285	64,263,368	135,563,232
Black	267,856	1129,307	3306,932	4743,254	3328,346	12,775,695	17,154,732
Asian	29,007	155,171	392,028	854,679	712,228	2143,113	5,083,769
Native American	10,030	33,101	63,304	110,277	61,509	278,221	1,736,823
Others	33,557	153,874	506,758	1077,356	842,613	2614,158	7,095,939
Hispanic	100,076	462,167	1528,885	2593,858	1816,292	6501,278	15,398,823
Color	402,059	1766,880	5228,348	8116,981	5787,093	21,301,360	38,983,632
White (%)	88.66	86.61	80.51	76.12	72.17	78.30	81.35
Black (%)	8.93	10.27	15.10	16.69	18.73	15.57	10.29
Asian (%)	0.97	1.41	1.79	3.01	4.01	2.61	3.05
Native American (%)	0.33	0.30	0.29	0.39	0.35	0.34	1.04
Others (%)	1.12	1.40	2.31	3.79	4.74	3.19	4.26
Hispanic (%)	3.34	4.20	6.98	9.13	10.22	7.92	9.24
Color (%)	13.40	16.07	23.87	28.57	32.57	25.95	23.39
Renter housing units (%)	25.11	28.02	31.89	36.70	38.20	34.12	31.26
College degree or higher (%)	18.73	21.62	21.43	22.14	21.36	21.59	19.71
Unemployed (%)	5.52	5.20	6.14	6.53	6.46	6.19	6.37
Poverty (%)	9.57	9.59	11.84	12.43	11.90	11.67	13.83
Mean household income ($)	65,336	68,761	67,584	68,689	69,938	68,549	60,443

Distance was measured between census-tract centroid points and NPP in miles. The category "Outside#" includes all areas within the U.S. that do not fall within a 50-mile radius of any one of the 65 U.S.-based NPPs. Mean household income is real dollar value as of 2010
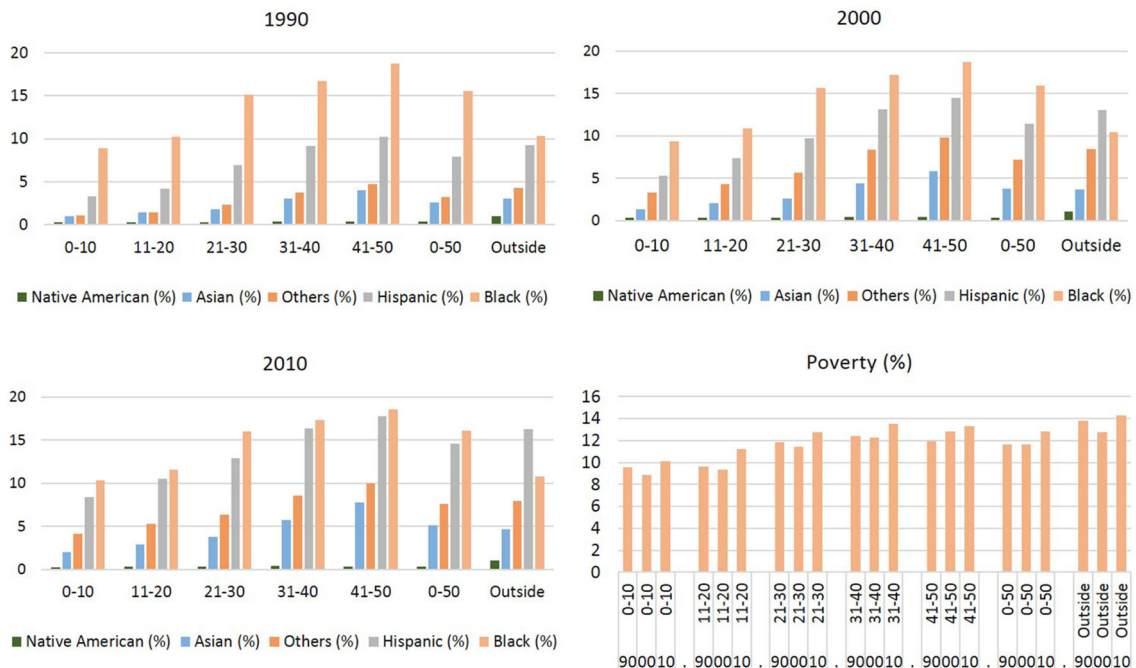
Data Source GeoLytics (2012a)

Fig. 2 Demographic trends (race/ethnicity) in the areas surrounding any one of the 65 U.S.-based commercial NPPs, as sorted by distance
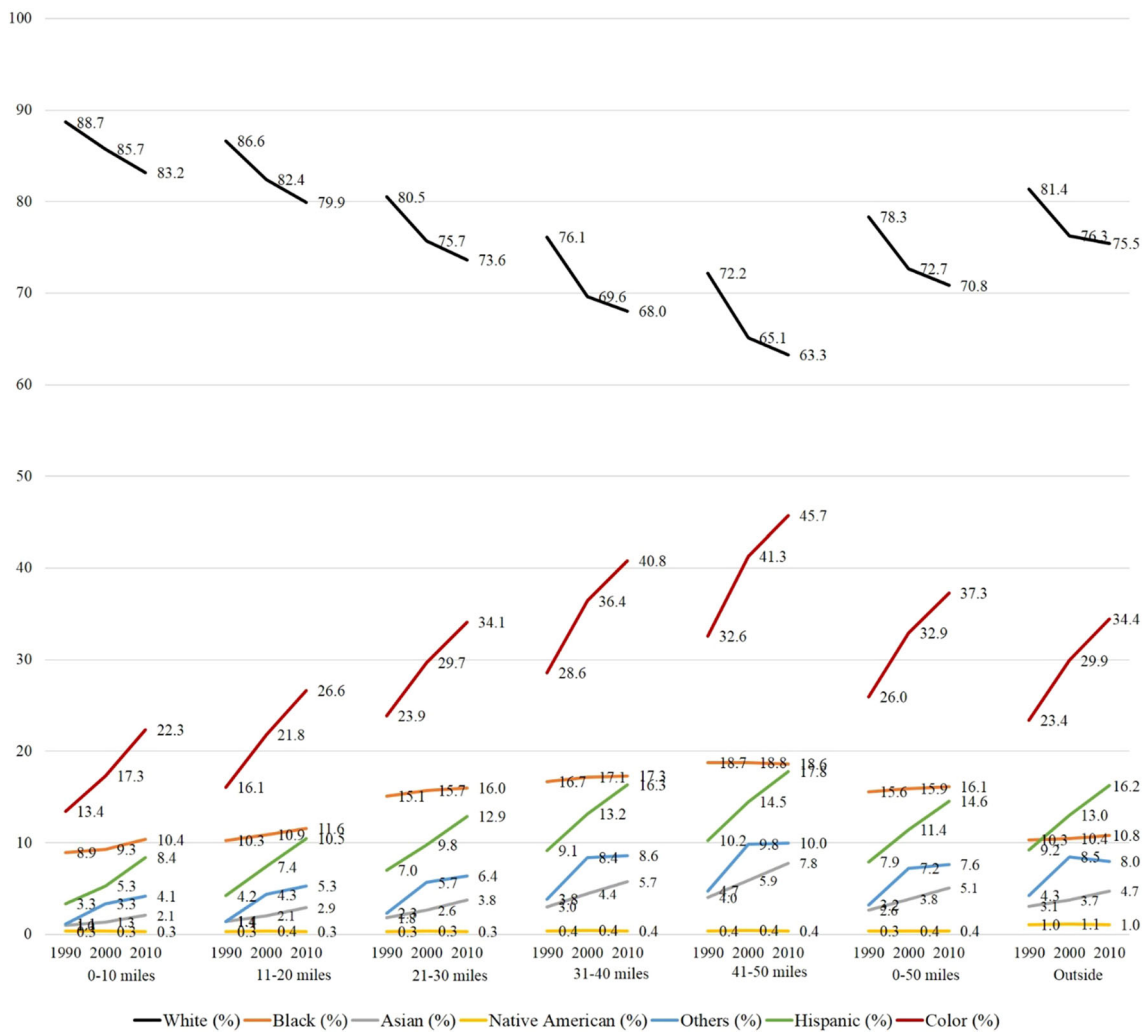
Fig. 3 Demographic trends (race/ethnicity) in the areas surrounding any one of the 65 U.S.-based commercial NPPs, as sorted by distance

This study also found that percent White was negatively associated with distance within 0–50 miles from a NPP—that is, in the nearby area the greater the distance from a NPP, the lower the percentage of White people living in the communities. For the 2010 data, percent White was observed as 83.17, 79.92, 73.63, 68.03, and 63.29 %, in the 0–10 miles, 11–20 miles, 21–30 miles, 31–40 miles, and 41–50 miles categories, respectively (Table 1). The percentages for other racial and ethnic groups—namely Black, Asian, Hispanic, and Native American—meanwhile, were positively associated with distance within 0–50 miles from a NPP; that is, the greater the distance from a NPP, the higher the percent of non-White peoples and households in the communities. Similarly, the percent of people living in poverty, the unemployment rate, the percent of people holding a college-degree, and the mean household income were all positively associated with distance from a NPP. In contrast, the percent of native-born citizens was negatively

associated with distance. Similar demographic patterns were observed in the U.S. Census data for the years 2000 (Table 2) and 1990 (Table 3), as well.

Interesting demographic trends emerged when examining the data over the past two decades (Figs. 2 and 3). First, there was a notable trend of decreasing percent White at every distance, with a corresponding increase in percent non-White over that same period (Fig. 2). A minimal increase is seen in both percent Black and percent Asian in each of the 3 years. From 1990 to 2000, the percent of people living in poverty and the percent unemployed showed a slight increase, while those same figures show a sharp increase from 2000 to 2010 (Fig. 3).

4.2 Overall Differences in the Demographic Characteristics

This section presents findings pertaining to the overall demographic characteristics of the populations analyzed,

sorted into two groups—those within a 50-mile radius of a NPP and those in the outside areas (Table 4). The analyses include 49,215 census tracts in the outside areas across the United States, and an additional 23,163 census tracts drawn from those areas within a 50-mile radius of a NPP. Unequal variance Welch t test was used for the analyses. The result shows that, as compared to the outside areas, the populations living within a 50-mile radius included a higher percent Black (6.86 %), percent Asian (0.39 %), and percent Color (4.37 %) as of 2010. The difference was statistically significant at the $p < 0.001$ level. In contrast, in the outlying areas the populations included higher percent White, percent Native American, percent Other, and percent Hispanic. Again, the difference was statistically significant at the $p < 0.001$ level. A similar pattern can be observed in data for the years 2000 and 1990, with the lone exception that percent Asian was higher in the outlying areas in those years. From 1990 to 2010, the disparity in percent Black, percent Asian, and percent Color between the two areas has continued to widen. In other words, there is an increasing trend to see a greater percent Black, percent Asian, and percent Color among the populations living within a 50-mile radius of a NPP.

5 Discussion and Conclusion

First, 8 % (300,801 square miles) of the total land area of the United States (3.80 million square miles) is occupied by host communities located within a 50-mile radius of a NPP. This means that the area that could be affected by NPPs and any accidents that might occur at them is objectively large. Even the definition of a 50-mile radius as the extent of the area that would be impacted remains open to debate given the new data still being generated and analyzed in the aftermath of the most recent core meltdown-type accident, at Fukushima NPP.

Table 4 Results of two independent-sample T tests (Welch's T test) calculated to identify differences in the demographic composition of populations living within a 50-mile radius of and populations living in the outlying areas surrounding a U.S.-based NPP as of 2010

		Count	SE	N1	Mean 1	N2	Mean 2	Diff.	t
2010	White	72,378	0.20	49,215	75.42	23,163	69.32	6.101***	(29.89)
	Black	72,378	0.18	49,215	11.42	23,163	18.28	−6.857***	(−38.52)
	Asian	72,378	0.07	49,215	4.38	23,163	4.77	−0.391***	(−5.56)
	Native American	72,378	0.04	49,215	1.14	23,163	0.36	0.782***	(21.09)
	Others	72,378	0.08	49,215	7.63	23,163	7.27	0.365***	(4.57)
	Hispanic	72,378	0.17	49,215	15.21	23,163	13.55	1.655***	(9.97)
	Color	72,378	0.24	49,215	33.78	23,163	38.15	−4.372***	(−18.13)
2000	White	72,865	0.21	49,551	76.59	23,314	71.85	4.742***	(23.03)
	Black	72,865	0.18	49,551	10.67	23,314	17.30	−6.628***	(−37.52)
	Asian	72,865	0.06	49,551	3.54	23,314	3.61	−0.078	(−1.30)
	Native American	72,865	0.04	49,551	1.19	23,314	0.42	0.774***	(20.84)
	Others	72,865	0.09	49,551	8.05	23,314	6.93	1.129***	(12.94)
	Hispanic	72,865	0.15	49,551	12.29	23,314	10.65	1.642***	(10.80)
	Color	72,865	0.24	49,551	29.26	23,314	33.28	−4.022***	(−17.06)
1990	White	72,704	0.20	49,403	82.23	23,301	78.47	3.764***	(19.06)
	Black	72,704	0.17	49,403	9.75	23,301	15.68	−5.928***	(−33.88)
	Asian	72,704	0.05	49,403	2.84	23,301	2.47	0.376***	(6.91)
	Native American	72,704	0.04	49,403	1.15	23,301	0.37	0.777***	(20.72)
	Others	72,704	0.07	49,403	4.04	23,301	3.05	0.984***	(14.14)
	Hispanic	72,704	0.13	49,403	8.93	23,301	7.55	1.381***	(10.50)
	Color	72,704	0.22	49,403	22.44	23,301	25.58	−3.145***	(−14.18)

Mean 1 = the mean percent demographic characteristics in outlying area across the United States

Mean 2 = the mean percent demographic characteristics in areas within a 50-mile radius of a NPP

Difference obtained by subtracting Mean 2 from Mean 1; (Mean 1 − Mean 2)

t statistics in parentheses

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

In addition to this large potentially impacted area, the findings also reveal that 96 million people out of a total population of 304 million live in host communities. This segment of the population is significantly larger than the estimated 22 million people who lived within three miles of a toxic release inventory (TRI) facility in the United States. (Bullard et al. 2007). The largest group of host communities—those within a 50-mile radius of Indian Point Nuclear Power Plant in New York—is home to approximately 15 million out of the 96 million people who live in such proximity to a U.S.-based NPP. The host communities include among their populations a lower percent White and a higher percent Black, Asian, and Color than compared to other communities.

The disparities in the demographic characteristics that exist between host and non-host communities are statistically significant. This large population size and the disparities in that population's demographic characteristics imply that particular racial minority groups are disproportionately shouldering the environmental hazards and risks that come attached to nuclear power. In addition, the large population living in host communities presents challenges in terms of disaster management, including in devising efficient and effective rescue and mitigation plans. The NRC emergency planning and preparation process appears not to take into account the sheer size of the potentially impacted population in its existing emergency evacuation, sheltering, and other action plans (U.S. NRC 2011a).

There is no detailed evacuation plan available for the host communities, especially in the most densely populated areas surrounding the Indian Point NPP. It is not an easy or simple task to evacuate or shelter some 15 million people. When people are gripped by panic, traffic congestion is inevitable. According to the notion of environmental justice as defined by the EPA, from a protection perceptive, environmental justice is achieved when everyone enjoys the same degree of protection from environmental and health hazards. Based on this study's statistical analyses, the bottom line conclusion is that there is no equal protection from the potential risks associated with commercial NPPs. The findings in this study provide a wake-up call for all concerned authorities to look carefully into issues associated with the increasing population involuntarily exposed to nuclear power plant-induced disasters for the past two decades.

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