The Vulnerability of Small Countries in the Event of a Major Nuclear Accident in Their Territory

Strategic Analysis and International Comparison

International Version of
"Switzerland's Vulnerability in the Event of a Major Nuclear Accident in Its Territory"

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The Vulnerability of Small Countries in the Event of a Major Nuclear Accident in Their Territory

1 EXECUTIVE SUMMARY

1.1 Introduction

This report compares the strategic environment of 194 nuclear power plants around the world. It classifies the power plants according to their strategic weakness and the level of vulnerability they may create, or not, in their respective countries in the event of a major nuclear accident given their proximity or distance from important urban areas. An event of this type would have a strategic impact on the social, economic, and political framework, the extent of which should be considered. The original version of this report focused on Switzerland (see the French and German versions); this version was adapted to study the concerns of small countries in general.

The primary conclusion is that some countries take an extraordinary risk given the abnormal threat that looms over them. In terms of population displacement, loss of territory, impoverishment, and weakened institutions, a major nuclear accident at one of the power plants at the top of the classification presented here is equivalent to the impact of a war.

This extraordinary strategic weakness is worrisome. It is becoming very serious since safety norms for existing nuclear power plants are not modeled on the norms that new plants must meet. In older model power plants, the redundancy of safety systems and the physical separation of emergency systems—in short, the safety requirements that constitute a quality, “in-depth defense”—are inferior to those required in new power plants, which further accentuates the aging of elements that cannot be updated. It is pertinent to discuss lower-cost safety standards for countries with older power plants and, in particular, a very high level of vulnerability to a major nuclear accident.

This version of the study examines only the vulnerability of countries based on the location of the power plant compared to the population and the most exposed urban areas. From a location standpoint (strategic weakness and vulnerability of the environment surrounding a nuclear power plant), several countries have a very high risk profile, including one power plant in Armenia, two in Taiwan (out of three), four in Switzerland, and two in Belgium. Other power plants in especially poor locations create a considerable risk in important countries given their proximity to important (strategic) urban areas. Other small and medium-size countries are seriously exposed, but to a lesser extent.

1.2 Scale of a major accident as applied in this study

A Level 7 accident based on the International Atomic Energy Agency’s International Nuclear and Radiological Event Scale (INES) is the reference point for this study. The Swiss Federal Nuclear Safety Inspectorate (ENSI) distinguishes three levels within Level 7 when analyzing threats to Swiss nuclear power plants: A4, A5, A6, with an A6 threat being the maximum level. To estimate the degree of various countries’ strategic weakness, it is worth paying special attention to the consequences of an A6 scenario.

Considering the size of a long-term evacuation zone, which would have a considerable, strategic impact on a country over many years, several official sources make it possible to conclude that it would be implemented at a radiation level above 555,000 becquerels per m^2 (555 kBq/m^2). Based on experience, a major nuclear accident could lead to an exclusion zone that measures 2,826 km^2 (30km radius) and 7,850 km^2 (50 km radius), or more.

A major nuclear accident can have a different impact depending on weather conditions, which necessarily affect the form of an exclusion zone and controlled zones where the population cannot attend to its business or move about normally. However, an international comparison demands the chosen criteria be standardized in order to apply them across all 194 power plants that were studied. In documenting the vulnerability of various countries, we are studying only two scenarios: a 30 km exclusion zone and a 50 km exclusion zone, considering borders between states only where it facilitates our work.[1]

1.3 International comparison of strategic weakness and potential vulnerability

The international comparison of countries' vulnerability to a major nuclear accident considers the eventual creation of a zone with a 30 km and 50 km radius around each of the 194 power plants. It documents the long-term pressure on a country after a radioactive cloud develops *and* the long-term soil deposits that would result. The health concerns caused by the passage of a radioactive cloud are significant, but this report is more interested in the strategic aspect of a long-term exclusion zone.

An international comparison requires a standardized matrix so all countries are analyzed in the same manner. We examined their situation by comparing the main strategic characteristics of the environment surrounding the power plants based on a radius of 30 km and 50 km respectively.

We also considered four different criteria to determine the final rankings of 194 nuclear power plants: 1, the impact on the surrounding population compared to the country's total population (*Table 2*); 2, the territorial impact of an exclusion zone in proportion to the country's size (*Table 3*); 3, the relative importance of urban areas and how many are located in a 30 km and 50 km radius as determined by comparing the populations of these areas to the country's population (population approach – *Table 5*); 4, the relative importance of urban areas and how many are located in a 30 km and 50 km radius, a metropolitan area approach that compares the population of urban areas to the population of the country's primary metropolitan area (*Table 6*). Each of these four strategic characteristics makes it possible to rank the 194 power plants, which makes it possible to assign a final ranking to each one based on the vulnerability of its strategic environment. The variety of approaches gives the final classification a certain level of strength (Table 7).

Two other tables offer information about the population residing near each nuclear power plant (Table 1), as well as about strategies for exporting the nuclear threat (Table 4). Table 4 shows that Luxembourg is most exposed to a major nuclear accident by the Cattenom power plant in France. The final classification (Table 7) is concerned only with a country's capacity to "self inflict" a major accident as a consequence of inadequate decisions (strategic error).

[1] To measure distance between nuclear power plants and cities, we used the "measure distance" function in Google Maps and calculated distances by going to the point at which a substantial proportion of the inhabited urban area (at least one quarter), as viewed by satellite, is included in a 30 km or 50 km radius (respectively).

All the results (7 tables)

MORAL RESPONSABILITY AND VULNERABILITY: Number of inhabitants in a 30 km radius around 194 active nuclear power plants (Data: Declan Butler [a])

Table 1: Number of inhabitants in a 30 km radius

Line No.	Nuclear Power Plant Name	Country Name	No. of inhabitants in a 30 km radius: No. of inhabitants [a]
1	Kanupp	Pakistan	8'346'926
2	Kuosheng	Taiwan	5'454'287
3	Jinshan - Chin Shan	Taiwan	4'687'065
4	Kori II / Kori	Korea, Rep.	3'410'020
5	Guangdong - Daya Bay	China	3'247'486
6	Lingao	China	3'106'385
7	Narora	India	2'243'522
8	Pickering	Canada	2'197'681
9	Philippsburg	Germany	1'743'695
10	Neckarwestheim	Germany	1'619'944
11	Doel	Belgium	1'511'575
12	Wolsong	Korea, Rep.	1'300'745
13	Qinshan	China	1'299'506
14	Indian Point	USA	1'075'040
15	Hartlepool	United Kingdom	1'062'217
16	Beznau	Switzerland	1'027'780
17	Tianwan	China	1'010'056
18	Limerick	USA	982'549
19	Fuqing	China	980'280
20	Kakrapar	India	963'906
21	Goesgen	Switzerland	959'787
22	Fessenheim	France	931'516
23	Tökai	Japan	919'437
24	Mühleberg	Switzerland	892'419
25	Three Mile Island	USA	836'919
26	Tihange	Belgium	836'375
27	Leibstadt	Switzerland	817'983
28	Cattenom	France	801'518
29	Metsamor - Armenia	Armenia	768'816
30	McGuire	USA	758'773
31	Kudankulam	India	751'613
	(Not published)	*(Not published)*	*(Not published)*
193	Wolf Creek	USA	13'185
194	Bilibino	Russian Fed.	276
	Fukushima Daïni*	Japan	204'250
	Fukushima Daïchi*	Japan	171'563

Table 1: Each of the 194 nuclear power plants has a given number of inhabitants living in a 30 km radius. The numbers above include populations living on the other side of national borders.

a) Data from Declan Butler *(Nature)*. http://www.nature.com/news/2011/110421/full/472400a.html. Declan Butler analyzed these data with Kytt MacManus and Liana Razafindrazay of Columbia University's Center for International Earth Science Information Network (CIESIN) using data from the NASA Socioeconomic Data and Applications Center. Data are from 2000 and 2010. For contributors and additional information, see: http://www.nature.com/news/2011/110421/full/472400a/box/1.html

* Nuclear power plants definitively shut down after a Level 7 accident as defined by the International Nuclear and Radiological Event Scale (INES).

STRATEGIC WEAKNESS AND VULNERABILITY: Population in a 30 km radius around active nuclear power plants (percentage of inhabitants compared to the population of the country where the plant is located)

Table 2: Percentage of the number of inhabitants in a 30 km radius

Line No.	Nuclear Power Plant Name	Country Name	Percentage of no. of inhabitants in a 30 km radius Percentage [a,b]	1 = maximum potential impact Rank
1	Metsamor - Armenia	Armenia	25.47%	1
2	Kuosheng	Taiwan	23.34%	2
3	Jinshan - Chin Shan	Taiwan	20.05%	3
4	Krsko**	Slovenia	16.15%	4
5	Doel**	Belgium	13.63%	5
6	Beznau	Switzerland	12.92%	6
7	Goesgen	Switzerland	12.06%	7
8	Mühleberg	Switzerland	11.22%	8
9	Leibstadt	Switzerland	10.28%	9
10	Tihange**	Belgium	7.54%	10
11	Bohunice	Slovakia	7.10%	11
12	Kori II / Kori	Korea, Rep.	6.65%	12
13	Pickering	Canada	6.16%	13
14	Mochovce	Slovakia	5.57%	14
15	Kanupp	Pakistan	4.44%	15
16	Dukovany	Czech Rep.	2.81%	16
17	Borssele**	Netherlands	2.62%	17
18	Temelin	Czech Rep.	2.57%	18
19	Wolsong	Korea, Rep.	2.54%	19
20	Philippsburg	Germany	2.13%	20
21	Neckarwestheim	Germany	1.98%	21
22	Kozlodui	Bulgaria	1.89%	22
23	Paks	Hungary	1.84%	23
24	Hartlepool	United Kingdom	1.66%	24
25	Wolsong-Shin	Korea, Rep.	1.46%	25
26	Fessenheim**	France	1.40%	26
27	Olkiluoto	Finland	1.37%	27
28	Darlington	Canada	1.22%	28
29	Cattenom**	France	1.20%	29
30	Ringhals	Sweden	1.05%	30
31	Bugey	France	1.05%	30
	(See appendix)	*(See appendix)*	*(See appendix)*	*(See appendix)*
193	Wolf Creek	USA	0.00%	193
194	Bilibino	Russian Fed.	0.00%	193
	Fukushima Daïni*	Japan	0.16%	
	Fukushima Daïchi*	Japan	0.13%	

Table 2: The rank of each of the 194 nuclear power plants is calculated by comparing the population living in a 30 km radius with the population of the country where the plant is located. In some cases, the number of inhabitants includes people living on other sides of the border.

a) The percentages above are calculated based on data from Declan Butler: http://www.nature.com/news/2011/110421/full/472400a.html / See links to the methodological indications in Table 1.

b) The number of inhabitants in a country used to calculate the percentages is from Wikipedia: http://fr.wikipedia.org (Jan. 2015)

* Nuclear power plants definitively shut down after a Level 7 accident as defined by the International Nuclear and Radiological Event Scale (INES).

** Nuclear power plants that threaten urban areas in other countries. (For details about these sites, see Table 4.)

STRATEGIC WEAKNESS AND VULNERABILITY: Territorial impact of an exclusion zone with a radius of 30 km (2826 km^2)

Table 3: Territory		Country Area [b]	Relative impact of a 2826 km^2 exclusion zone	1 = maximum potential impact
Line	Country [a]	km^2	%	Rank
1	Slovenia	20'273	13.94%	1
2	Armenia	29'743	9.50%	2
3	Belgium	30'528	9.26%	3
4	Taiwan	36'193	7.81%	4
5	Switzerland	41'285	6.85%	5
6	Netherlands	41'530	6.80%	6
7	Slovakia	49'035	5.76%	7
8	Czech Republic	78'870	3.58%	8
9	Hungary	93'029	3.04%	9
10	Korea, Rep.	99'274	2.85%	10
11	Bulgaria	110'944	2.55%	11
12	Romania	238'391	1.19%	12
13	United Kingdom	243'610	1.16%	13
14	Finland	338'144	0.84%	14
15	Germany	357'021	0.79%	15
16	Japan	377'914	0.75%	16
17	Sweden	449'965	0.63%	17
18	Spain	505'911	0.56%	18
19	Ukraine	603'549	0.47%	19
20	France	671'308	0.42%	20
21	Pakistan	796'095	0.35%	21
22	South Africa	1'219'912	0.23%	22
23	Iran, Islamic Rep.	1'648'195	0.17%	23
24	Mexico	1'964'375	0.14%	24
25	Argentina	2'780'400	0.10%	25
26	India	3'287'263	0.09%	26
27	Brazil	8'514'576	0.03%	27
28	USA	9'629'048	0.03%	27
29	China	9'670'009	0.03%	27
30	Canada	9'984'670	0.03%	27
31	Russian Fed.	17'125'242	0.02%	31

Table 3: An exclusion zone of 2826 km^2 has a greater territorial impact on smaller countries.

a) International Atomic Energy Agency, *Annual Report 2013*, Table A9: "Nuclear power reactors in operation in the world" (as of 31 December 2013) p. 113 (Data are from the IAEA's Power Reactor Information System – PRIS - http://www.iaea.org/pris)

b) Country area in km^2: http://fr.wikipedia.org (Nov. 2014)

c) We are differentiating China from Taiwan

STRATEGIC WEAKNESS AND VULNERABILITY: 8 nuclear power plants that threaten foreign urban areas (distance <= 50 km)

Table 4: Exporting the threat		Population Urban Area (UA) Rank 1		Population Urban Area (UA) Rank 2		Population Urban Area (UA) Rank 3		Proximity of urban areas
Nuclear Power Plant	Country Threatened	Dist. to plant (km)		Dist. to plant (km)		Dist. to plant (km)		Illustrative default case (minimum 8)
		<=30	31 to 50	<=30	31 to 50	<=30	31 to 50	
Name (Location)	Name	No. of UA Rank 1	No. of UA Rank 1	No. of UA Rank 2	No. of UA Rank 2	No. of UA Rank 3	No. of UA Rank 3	
Cattenom (France)	Luxembourg	1				4	1	101
Cattenom (France)	Germany						1	9
Cattenom (France)	France							8
Krsko (Slovenia)	Croatia		1					58
Krsko (Slovenia)	Slovenia					3	3	20
Borssele (Netherlands)	Belgium				2		2	46
Borssele (Netherlands)	Netherlands					1		11
Chooz (France)	Belgium				1		1	27
Chooz (France)	France							8
Fessenheim (France)	Switzerland				1			26
Fessenheim (France)	France							8
Emsland (Germany)	Netherlands						2	10
Emsland (Germany)	Germany						1	9
Doel (Belgium)	Netherlands						2	10
Doel (Belgium)	Belgium			1	1	1		53
Tihange (Belgium)	Netherlands						1	9
Tihange (Belgium)	Belgium			1			1	33

Table 4: Zones measuring 30 km and 50 km are defined in the hypothesis of creating an exclusion zone in territories measuring more than 555 kBq/m^2 long term after a major nuclear accident. The 8 power plants listed above are located near national borders where the potential exists for this type of threat to be exported. This table illustrates a strategic game in which some countries determine the location of their power plants by seeking to preserve their most important urban areas. The rank of each urban area is calculated by comparing its population to that of the main metropolitan area of the country where it is located (see Table 6).

STRATEGIC WEAKNESS AND VULNERABILITY: Ranking of 194 active nuclear power plants according to their proximity to the main urban areas in the countries where they are located (the rank of each urban area is calculated based on the country's population.)

Table 5: Cities according to country population			Population Urban Area (UA) Rank 1		Population Urban Area (UA) Rank 2		Population Urban Area (UA) Rank 3		Proximity to main urban areas (Vulnerability)	
Line	Nuclear Power Plant	Country	Dist. to plant (km)		Dist. to plant (km)		Dist. to plant (km)		Illustrative default case (Minimum 8)	1 = high vulnerability
			<=30	31 to 50	<=30	31 to 50	<=30	31 to 50		
No.	Name	Name	No. UA Rank 1	No. UA Rank 1	No. UA Rank 2	No. UA Rank 2	No. UA Rank 3	No. UA Rank 3		Rank
1	Beznau	Switzerland	1			1		1	107	1
2	Metsamor	Armenia	1				1	1	93	2
3	Jinshan - Chin Shan	Taiwan	1				1		92	3
4	Kuosheng	Taiwan	1				1		92	3
5	Kanupp	Pakistan	1						88	5
6	Pickering	Canada	1						88	5
7	Leibstadt	Switzerland		1		1		1	77	7
8	Goesgen	Switzerland		1		1		1	77	7
9	Darlington	Canada		1					58	9
10	Doel**	Belgium			1	1	1		54	10
11	Mühleberg	Switzerland			1		3	1	45	11
12	Kori II / Kori	Korea, Rep.			1		1		36	12
13	Tihange**	Belgium			1			1	33	12
14	Koeberg	South Africa			1				32	14
15	Neckarwestheim	Germany			1				32	14
16	Indian Point	USA				1			26	16
17	Ringhals	Sweden				1			26	16
18	Brokdorf	Germany				1			26	16
19	Dukovany	Czech Rep.				1			26	16
20	Philippsburg	Germany					3		20	20
21	St-Alban	France					2		16	21
22	Olkiluoto	Finland					2		16	21
23	Krsko**	Slovenia					1	3	15	23
24	Bohunice	Slovakia					1	2	14	24
25	Hartlepool	United Kingdom					1	1	13	25
26	Hinkley Point B	United Kingdom					1	1	13	25
27	Mochovce	Slovakia					1	1	13	25
28	Catawba	USA					1		12	28
29	McGuire	USA					1		12	28
30	Turkey Point	USA					1		12	28
31	Borssele**	Netherlands					1		12	28
32	Wolsong	Korea, Rep.					1		12	28
33	Wolsong-Shin	Korea, Rep.					1		12	28
34	Grafenrheinfeld	Germany					1		12	28
35	Bugey	France					1		12	28
36	St-Laurent	France					1		12	28
37	Temelin	Czech Rep.					1		12	28
38	Loviisa	Finland						2	10	38
39	Beaver Valley	USA						1	9	39
40	Dresden	USA						1	9	39
41	Enrico Fermi	USA						1	9	39
42	Limerick	USA						1	9	39
43	Monticello	USA						1	9	39
44	Peach Bottom	USA						1	9	39
45	Perry	USA						1	9	39
46	Prairie Island	USA						1	9	39
47	Hunterston	United Kingdom						1	9	39
48	Torness	United Kingdom						1	9	39
49	Zaporizhia	Ukraine						1	9	39
50	Beloyarsky	Russian Fed.						1	9	39
51	Novovoronezh	Russian Fed.						1	9	39
52	Novovoronezh-2	Russian Fed.						1	9	39
53	Cernavoda	Romania						1	9	39
54	Hanbit	Korea Rep.						1	9	39
55	Genkai	Japan						1	9	39
56	Onagawa	Japan						1	9	39
	See appendix	*See appendix*					*See appendix*	*See appendix*	*See appendix*	*See appendix*
193	Atucha	Argentina							8	65
194	Embalse	Argentina							8	65
	Chernobyl*	Ukraine							8	
	Fukushima Daïchi*	Japan							8	
	Fukushima Daïni*	Japan							8	

Table 5: The rank of each urban area is calculated in comparison to the country's population. The distance from urban areas to nuclear power plants is measured based on the location of the first densely constructed suburb. Of 194 nuclear power plants, 9 are less than 50 km from Rank 1 cities in their own country; 167 plants have at most one Rank 3 city within less than 30 km (6/7). However, 130 plants do not have a Rank 3 city within less than 50 km (2/3). This table does not take into consideration urban areas located in another country given the strategic perspective of the analysis.

* Nuclear power plants definitively shut down after a Level 7 accident as defined by the International Nuclear and Radiological Event Scale (INES).

** Nuclear power plants that threaten urban areas in other countries. These urban areas are not included in this table. (For details about these sites, see Table 4.)

STRATEGIC WEAKNESS AND VULNERABILITY: Ranking of 194 active nuclear power plants according to their proximity to the main urban areas of the country in which the plant is located (the rank of each urban area is based on the country's main metropolitan area.)

Table 6: Cities according to metropolitan area approach			Population Urban Area (UA) Rank 1		Population Urban Area (UA) Rank 2		Population Urban Area (UA) Rank 3		Proximity to main urban areas (Vulnerability)	
Line	Nuclear Power Plant (Metropolitan Area Exposed)	Country	Dist. to plant (km) <=30	Dist. to plant (km) 31 to 50	Dist. to plant (km) <=30	Dist. to plant (km) 31 to 50	Dist. to plant (km) <=30	Dist. to plant (km) 31 to 50	Illustrative default case (Minimum 8)	1 = high vulnerability
No.	Name	Name	No. of UA Rank 1	No. of UA Rank 1	No. of UA Rank 2	No. of UA Rank 2	No. of UA Rank 3	No. of UA Rank 3		Rank
1	Beznau (Zürich)	Switzerland	1			1		1	107	1
2	Metsamor (Erevan)	Armenia	1				1	1	93	2
3	Kuosheng (Taipei)	Taiwan	1				1		92	3
4	Jinshan (Taipei)	Taiwan	1				1		92	3
5	Koeberg (Cape Town)	South Africa	1						88	5
6	Kanupp (Karachi)	Pakistan	1						88	5
7	Pickering (Toronto)	Canada	1						88	5
8	Leibstadt (Zürich)	Switzerland		1		1		1	85	8
9	Goesgen (Zürich)	Switzerland		1		1		1	85	8
10	Indian Point (New-York)	USA		1					66	10
11	Brokdorf (Hamburg)	Germany		1					66	10
12	Darlington (Toronto)	Canada		1					66	10
13	Bohunice	Slovakia			1	1		2	65	13
14	Doel	Belgium			1	1			63	14
15	Mühleberg	Switzerland			1		3	1	58	15
16	Philippsburg	Germany			1		2	1	54	16
17	Neckarwestheim	Germany			1		1	1	50	17
18	Kori II / Kori	Korea, Rep.			1		1		49	18
19	Mochovce	Slovakia			1			2	47	19
20	Tihange**	Belgium			1			1	46	20
21	Turkey Point	USA			1				45	21
22	Limerick	USA				2			44	22
23	Enrico Fermi	USA				2			44	22
24	Dresden	USA				2			44	22
25	Lingao	China				2			44	22
26	Guangdong - Daya Bay	China				2			44	22
27	Zaporizhia	Ukraine				1	1		30	27
28	Grohnde	Germany				1		1	27	28
29	Ringhals	Sweden				1			26	29
30	Madras	India				1			26	29
31	Kakrapar	India				1			26	29
32	Dukovany	Czech Rep.				1			26	29
33	Grafenrheinfeld	Germany					2	1	17	33
34	St-Alban	France					2		16	34
35	Krsko**	Slovenia					1	2	14	35
36	Hinkley Point B	United Kingdom					1	1	13	36
37	Gundremmingen	Germany					1	1	13	36
38	Waterford	USA					1		12	38
39	Shearon Harris	USA					1		12	38
40	R. E. Ginna	USA					1		12	38
41	McGuire	USA					1		12	38
42	Fort Calhoun	USA					1		12	38
43	Catawba	USA					1		12	38
44	Borssele**	Netherlands					1		12	38
45	Wolsong-Shin	Korea, Rep.					1		12	38
46	Wolsong	Korea, Rep.					1		12	38
47	Bushehr	Iran					1		12	38
48	Bugey	France					1		12	38
49	Temelin	Czech Rep.					1		12	38
50	Sanmen	China						2	10	50
51	Surry	USA						1	9	51
52	Prairie Island	USA						1	9	51
53	Perry	USA						1	9	51
54	Peach Bottom	USA						1	9	51
	See appendix	*See appendix*					*See appendix*	*See appendix*	*See appendix*	*See appendix*
191	Kozlodui	Bulgaria							8	79
192	Angra	Brazil							8	79
193	Embalse	Argentina							8	79
194	Atucha	Argentina							8	79
	Fukushima Daiini*	Japan							8	
	Fukushima Daichi*	Japan							8	
	Chernobyl*	Ukraine							8	

Table 6: The rank of each urban area is calculated in comparison to the country's main metropolitan area. The distance from urban areas to nuclear power plants is measured based on the location of the first densely constructed suburb. Of 194 nuclear power plants, 12 are less than 50 km from Rank 1 cities in their own country; 156 plants have at most one Rank 3 city within 30 km or 50 km (4/5). However, 116 plants do not have any Rank 3 cities within less than 50 km (3/5). This table does not take into consideration urban areas located in another country given the strategic perspective of the analysis.

* Nuclear power plants definitively shut down after a Level 7 accident as defined by the International Nuclear and Radiological Event Scale (INES).

** Nuclear power plants that threaten urban areas in other countries. These urban areas are not included in this table. (For details about these sites, see Table 4.)

STRATEGIC WEAKNESS AND VULNERABILITY: Vulnerability of 31 countries in the event of a Level 7 major nuclear accident according to the INES at one of their active nuclear reactors.

Table 7: Summary of Tables 2, 3, 5, and 6			Vulnerability of population	Vulnerability according to territory	Rank of 194 nuclear power plants based on their proximity to main urban areas		Overall vulnerability	
			Percentage of population living in a 30 km radius of a nuclear power plant [a]	Impact of 2826 km^2 exclusion zone	Note: Rank of each urban area depends on each country's population ("national population" approach)	Note: Rank of each urban area depends on the population of the country's metropolitan area ("metropolitan area" approach)	Potential vulnerability of each plant	Final rank: 1 = high vulnerability
Line No.	Nuclear Power Plant Name	Country Name	(see Table 2) Rank	(see Table 3) Rank	(see Table 5) Rank	(see Table 6) Rank	Cumulative rank Illustrative default case	Final rank
1	Metsamor	Armenia	1	2	2	2	7	**1**
2	Kuosheng	Taiwan	2	4	3	3	12	**2**
3	Jinshan - Chin Shan	Taiwan	3	4	3	3	13	**3**
4	Beznau	Switzerland	6	5	1	1	13	**3**
5	Goesgen	Switzerland	7	5	8	8	28	**5**
6	Leibstadt	Switzerland	9	5	7	8	29	**6**
7	Doel	Belgium	5	3	9	14	31	**7**
8	Mühleberg	Switzerland	8	5	10	15	38	**8**
9	Tihange**	Belgium	10	3	12	20	45	**9**
10	Kanupp	Pakistan	15	21	5	5	46	**10**
11	Pickering	Canada	13	27	5	5	50	**11**
12	Kori II / Kori	Korea, Rep.	12	10	11	18	51	**12**
13	Bohunice	Slovakia	11	7	24	13	55	**13**
14	Krsko**	Slovenia	4	1	23	35	63	**14**
15	Mochovce	Slovakia	14	7	25	19	65	**15**
16	Neckarwestheim	Germany	21	15	14	17	67	**16**
17	Dukovany	Czech Rep.	16	8	16	29	69	**17**
18	Philippsburg	Germany	20	15	20	16	71	**18**
19	Darlington	Canada	28	27	8	9	72	**19**
20	Borssele**	Netherlands	17	6	28	38	89	**20**
21	Ringhals	Sweden	30	17	16	29	92	**21**
22	Brokdorf	Germany	52	15	16	9	92	**21**
23	Temelin	Czech Rep.	18	8	28	38	92	**21**
24	Koeberg	South-Africa	52	22	14	5	93	**24**
25	Wolsong	Korea, Rep.	19	10	28	38	95	**25**
26	Wolsong-Shin	Korea, Rep.	25	10	28	38	101	**26**
27	Hinkley Point B	United Kingdom	34	13	25	36	108	**27**
28	St-Alban	France	33	20	21	34	108	**27**
29	Indian Point	USA	57	27	16	9	109	**29**
30	Hartlepool	United Kingdom	24	13	25	51	113	**30**
31	Olkiluoto	Finland	27	14	21	51	113	**30**
32	Grafenrheinfeld	Germany	40	15	28	33	116	**32**
33	Bugey	France	30	20	28	38	116	**32**
34	Zaporizhia	Ukraine	36	19	39	27	121	**34**
35	Grohnde	Germany	42	15	39	28	124	**35**
36	Gundremmingen	Germany	46	15	39	36	136	**36**
37	Hunterston	United Kingdom	39	13	39	51	142	**37**
38	Cernavoda	Romania	41	12	39	51	143	**38**
39	Emsland**	Germany	43	15	39	51	148	**39**
40	Limerick	USA	61	27	39	22	149	**40**
41	Hanbit	Korea, Rep.	58	10	39	51	158	**41**
42	Guangdong - Daya Bay	China	73	27	39	22	161	**42**
43	Turkey Point	USA	88	27	28	21	164	**43**
44	Lingao	China	76	27	39	22	164	**43**
45	McGuire	USA	73	27	28	38	166	**45**
46	Khmelnytskyi	Ukraine	35	19	65	51	170	**46**
47	Catawba	USA	78	27	28	38	171	**47**
48	Loviisa	Finland	43	14	38	79	174	**48**
49	Paks	Hungary	23	9	65	79	176	**49**
50	St-Laurent	France	50	20	28	79	177	**50**
51	Kozlodui	Bulgaria	22	11	65	79	177	**50**
52	Isar	Germany	54	15	65	51	185	**52**
53	Genkai	Japan	81	16	39	51	187	**53**
54	Heysham	United Kingdom	32	13	65	79	189	**54**
55	Fessenheim**	France	26	20	65	79	190	**55**
56	Le Blayais	France	81	20	39	51	191	**56**
	See appendix	*See appendix*	*See appendix*	*See appendix*	*See appendix*	*See appendix*	*See appendix*	*See appendix*
193	Wolf Creek	USA	193	27	65	79	364	**193**
194	Bilibino	Russian Fed.	193	31	65	79	368	**194**

Table 7 summarizes the main results of Tables 2, 3, 5, and 6. It merges approaches that identify potential vulnerability based on the number of inhabitants living near a nuclear power plant (Table 2), territorial impact (Table 3), and urban areas near plants (Tables 5 and 6). The final rank can be considered robust.

a) The primary data from Table 1 are from Declan Butler's article in *Nature:* http://www.nature.com/news/2011/110421/full/472400a.html

** Nuclear power plants that threaten urban areas in other countries. (For details about these sites, see Table 4.)

1.4 Analysis of the results

The top three positions in the final classification (see Table 7) are Metsamor (Armenia), Kuosheng and Jinshan (Taiwan), and Beznau (Switzerland), which shared the third position. Positions 5 and 6 are held by power plants in Gösgen and Leibstadt (Switzerland); Doel (Belgium) is 7, Mühleberg (Switzerland) is 8, and Tihange (Belgium) is 9. Further analysis would make it possible to refine these rankings; however, it would be unlikely to change them. We note that one of Taiwan's power plants, Maanschan, ranks 110 due to its distance from any major urban area.

Beginning with the 10th rank, a second group of medium and large countries has nuclear power plants with the potential to afflict very high levels of strategic damage, including Kanupp (Pakistan), Kori (Korea), and Pickering (Canada). However, these countries will have less difficulty recovering than countries in the first group described above.

The third group, which is also comprised of small countries, has less vulnerability than the first group of small countries, but perhaps greater vulnerability than the second group (additional studies would be required to decide). Their vulnerability is considerable due to power plants at Krsko in Slovenia (14th) and at Bohunice and Mochovce in Slovakia (13th and 15th).

The fourth group includes nuclear power plants in medium-size countries, beginning with Neckarwestheim (16th), Dukovany (16th), Philippsburg (18th), and Darlington (19th) and ending with Borssele (20th) in the Netherlands, a country that is just as small as Switzerland, but that has twice as many people. Vulnerability is very important for international comparison.

A sixth group begins with Ringhals (21st) in Sweden and includes German, Czech, South African, French, and U.S. sites, creating another potentially vulnerable situation of considerable size. The sixth group includes sites up to Indian Point (29th), the last power plant that is less than 50 km from a Rank 1 city.

The seventh group includes Hartelpool (30th, United Kingdom), Olkiluoto (also 30th, Finland), and Grafenrheinfeld (32nd, Germany). It ends with Heysham (54th, United Kingdom), and Fessenheim and Le Blayais (55th and 56th, France).

The seventh group of power plants still imposes a significant strategic risk on the countries in which they are located, but to a lesser degree than for countries in the first group. The results show the country's size does not determine everything, even if it plays an important role. Please refer to the Appendix for the rest of the classification.

1.5 Results: Distancing nuclear power plants is a customary safety standard

In general, careful consideration of a nuclear power plant's location makes it possible to limit a country's vulnerability to a major accident. The following results reveal an implicit, customarily used safety standard that aims to distance power plants from heavily populated areas to limit a country's vulnerability. To illustrate this observation using a small country as an exception, Switzerland's results are described below.

	✈ CUSTOMARY SAFETY STANDARD ✈	✈ CURRENT SITUATION IN SWITZERLAND ✈
1	130 nuclear power plants have fewer than 400,000 inhabitants within a 30 km radius, (2/3 of all plants). Half of all plants have fewer than 222,000 inhabitants in a 30 km radius.	Swiss nuclear power plants have between 1,027,780 inhabitants (Beznau) and 817,983 inhabitants (Leibstadt) within a 30 km radius.
2	In a 30 km radius, 5/6 of the world's nuclear power plants expose less than 1% of the population of the country where they are located.	Swiss nuclear plants expose between 12.92% (Beznau) and 10.28% (Leibstadt) of the country's population.
3	If exclusion zones with a 30 km radius (2826 km^2) were established for the 194 nuclear power plants in the world, 161 of them (5/6) would impact less than 1% of a country's territory.	Switzerland would lose more than 6.5% of its territory.
4	156 of 194 of the world's nuclear power plants have, at most, one Rank 3 city within 30 or 50 km (4/5 or 80%).	Three of Switzerland's nuclear power plants have one Rank 1 urban area within 50 km, one Rank 2, and one Rank 3. The fourth plant also has a Rank 2 city that is the federal capital, plus four Rank 3 urban areas.

Table 8: If we look at the type of potential vulnerability presented by the world's nuclear power plants, only a minority impose a serious strategic threat to the country in which they are located. The most significant factor on Table 8 is the fourth line: 80% of the world's nuclear power plants have, at most, one Rank 3 city within 30 or 50 km. Yet, power plants in several small countries—Switzerland is just one example—do not respect this international standard, which creates an abnormal strategic weakness, made worse by old nuclear plants in their territory (with standards that are well below new plants).

In general, countries with nuclear power plants located near Rank 1 or Rank 2 urban areas live with a considerable threat that is far beyond normal on the global scale. This fact is further aggravated when power plants are modeled on older designs with all their related architectural flaws.

1.6 Remarks

International practice is dominated by distancing nuclear power plants from important urban areas with respect to a country's size. This connection is real and has been customarily followed.

After examining the literature of official agencies on this issue and applying their conclusions to small countries, nearly all of a country impacted by a major accident will be labeled a disaster zone for an undetermined period of time (several decades or even longer). Strategic weakness further aggravates a population's situation: a major accident destabilizes political institutions, heightening the damage to the affected population, which can no longer depend on national solidarity.

In addition to the nuclear power plants in small countries at the top of the ranking in terms of strategic weakness (Armenia, Taiwan, Switzerland, Belgium) and plants in small countries that are slightly less exposed (Slovakia, Slovenia, the Netherlands, Czech Republic), medium and large countries are also in a very strategically weak position given the location of some of their sites.

Among those are: Kanupp (Pakistan); Pickering and Darlington (Canada); Neckarwestheim, Philippsburg, and Brokdorf (Germany); Koeberg (South Africa);

Wolsong and Wolsong Shin (South Korea); Ringhals (Sweden); Hinkley Point B and Hartlepool (UK); St-Alban and Bugey (France); Indian Point (United States); and Olkiluoto (Finland). These sites potentially create the most vulnerability for their respective countries; however, they have other power plants that are less problematic from this standpoint. More detailed studies would make it possible to refine the classification.

1.7 Recommendation

The most vulnerable states should align the safety level of their nuclear power plants to the safety level of new plants (including the physical separation of safety systems—no matter the price) and, if this is not possible, close older sites as soon as possible. Following the Fukushima disaster, Germany definitively closed seven (the least reliable) of its seventeen reactors, while Japan closed all its sites (only one has come back online as of our publication date, September 2015). This method implies replacing the missing energy by rationalization measures, by developing alternative energy sources, or even by building new nuclear power plants, if problems associated with uranium mining operations and nuclear waste are resolved.[2]

When a country's nuclear power plants accumulate two significant flaws, the technical safety measures taken in older plants are not proportional to the country's real situation and are below expected standards (undersizing). These countries are taking a considerable strategic risk.

When a country is especially vulnerable to a major nuclear accident (the top 35 out of 194 plants fall into this category), especially if they are in the top 10, it must align its power plants with the safety criteria of new nuclear power plants. If it cannot align the safety of its plants with this level and it considers its territorial integrity, political independence, freedoms, prosperity, and the physical and mental integrity of its population as assets that deserve protection, it must close its nuclear power plants as quickly as possible and implement an alternative energy policy.

In terms of nuclear energy, a small country is foolhardy and irresponsible when it adopts safety standards that are valid for older nuclear power plants in much larger and more resilient countries than itself in the event of a major nuclear accident. Medium and large countries are also foolhardy and irresponsible if they continue to operate nuclear power plants in proximity to their major urban centers.

[2] The issue of definitively storing nuclear waste and the environmental consequences of mining uranium are not within the scope of this study.

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