Shifting Public Perceptions of Nuclear Risk

CHERNOBYL'S

TASS FROM SOVFOTO

Far left, the shift chief at Chernobyl's Unit No. 1 reactor checks the radiation level at the rods' heads. Near left, a German reporter interviews an evacuee after the accident.

OTHER LEGACY

By Christoph Hohenemser and Ortwin Renn

The reactor accident at Chernobyl in April 1986 involved the largest release of radioactivity ever recorded in one technological disaster.[1] Today, two years later, it is clear that the event involved a "worst-case" accident in which a large reactor with a mature fuel inventory breached containment and released several percent of its radionuclide inventory. Measured in terms of the radionuclide cesium 137, which dominates the long-term biological consequences, the total release of radioactivity was equivalent to the fallout from several dozen Hiroshima bombs.

The physical causes of the accident, the Soviet emergency response, the worldwide fallout, and the expected health effects have been discussed in a number of official reports.[2] The record shows that the accident resulted from a combination of major design flaws and management errors; that favorable weather and a highly competent Soviet emergency response—particularly in relation to victims of acute radiation exposure—limited immediate fatalities to 31; and that the most significant impact may be distant fallout that reached most parts of the Northern Hemisphere.

What is less obvious from the official story is that the accident at Chernobyl led to the largest uncontrolled experiment in risk perception and risk management ever conducted. In this experiment, nearly 400 million people worldwide were exposed to varying levels of fallout from which they currently suffer renewed anxiety and doubt about nuclear power. In addition, it is possible that the attendant exposure will result in thousands of delayed cancer fatalities.

Responses to the accident varied: individuals acted on their own, national governments took a wide range of protective actions, and national publics underwent substantial changes in their evaluation of nuclear power. A number of accounts of the accident argue that governments and the public were overwhelmed by the transnational impact of the accident, and that their response was in some sense irrational or exaggerated.[3]

This article describes the essential features of what is now known about the radiation release at Chernobyl, its worldwide dispersion, the resulting exposures, and the expected health consequences (see box on page 44 for a related discussion). With this basis the fallout exposure is related to changes in public attitudes about nuclear power, to the extent of protective action achieved, and to the level of commitment to nuclear power in several countries. This analysis allows a number of questions to be posed, as follows:

- Were shifts in public opinion related to the level of exposure, and if so, what does this suggest?
- Were protective actions, as measured by radiation exposure averted (dose savings), proportional to the danger posed?
- Were protective actions related to the change in public attitudes toward nuclear power?
- Was a country's degree of commitment to nuclear energy, as measured by the nuclear share of electricity generation, a factor in its response to the Chernobyl accident?

Analysis of these questions, which is largely based on data for the Western democracies, suggests that, with some significant exceptions, both public and government responses were surprisingly

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rational in that they were proportional to the public's level of exposure. This finding speaks in turn to the central importance of public information in fashioning a response to risky technology.

Fallout and Health Effects

At the time of the accident, the core of the Chernobyl reactor, consisting of a graphite moderator interlaced with water-cooled fuel rods, contained 1,659 uranium oxide fuel assemblies with an average age of 600 days.[4] Under these conditions most of the short-lived radionuclides had decayed, but virtually all of the long-lived radionuclides such as cesium 137 (half-life of 30 years); strontium 90 (half-life of 27.7 years); and plutonium 239 (half-life of 24,000 years) remained.

Based on early fallout measurements in West Germany,[5] it was concluded in June 1986 that the Chernobyl accident was equivalent to a worst-case accident in a Western-style water-moderated reactor, as described in 1975 by the American Physical Society.[6] Subsequent analysis of the Soviet data[7] and detailed dispersion studies of fallout outside the Soviet Union[8] showed that this early estimate was close to correct.[9]

A comparison of the Chernobyl release and the worst-case Western core-melt accident is shown (see Figure 1 on this page). The figure indicates that 100 percent of the noble gases; as much as 50 percent of the iodines, telluriums, and cesiums; and 3 to 6 percent of all other materials in the core were released. The most significant deviation from the Western worst-case accident scenario occurs for the transuranic elements, or nonvolatile oxides, of which the Chernobyl accident released about 3 percent of those in the core, irrespective of composition. This deviation is due to the fact that the Chernobyl accident involved a complex interaction between hot steam, graphite, and the uranium oxide fuel rods that led to the release of a significant fraction of undifferentiated spent fuel without significant core melting.[10]

The structure of the distant dispersion, which was dominated by cesium 137 and iodine 131 with little strontium 90, re-

FIGURE 1. Comparison of Chernobyl release to the putative worst-case light water accident PWR–2.

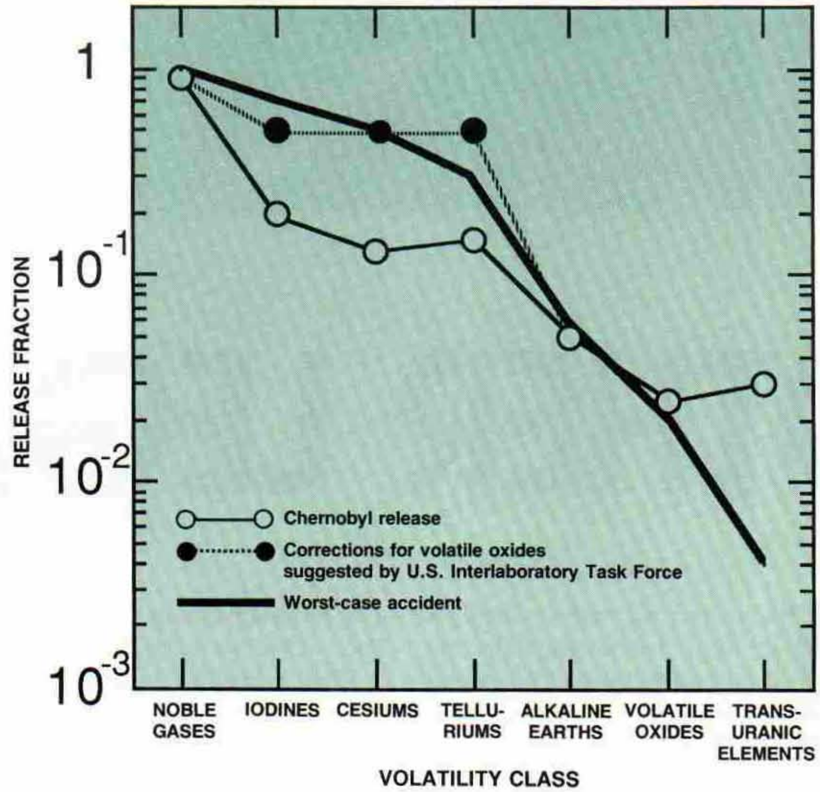
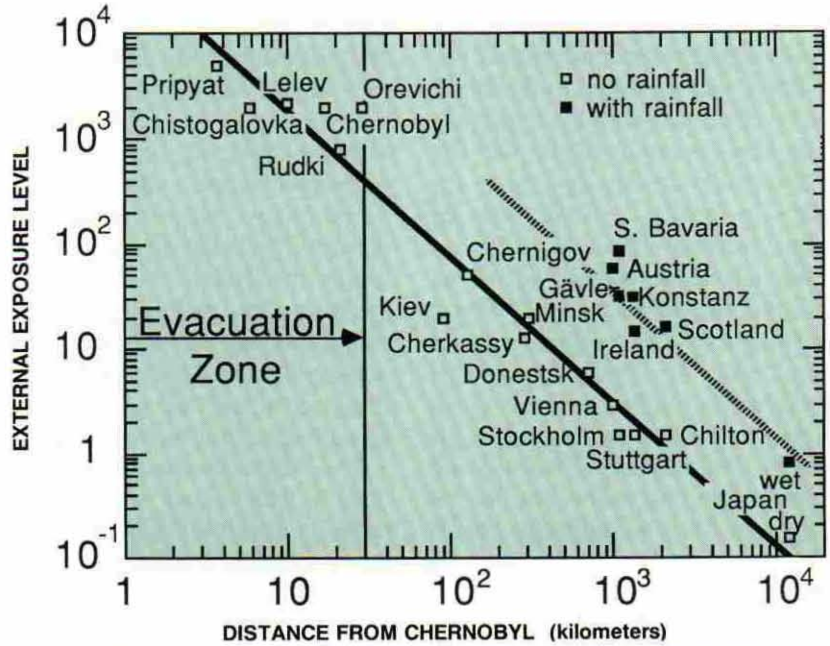


FIGURE 2. External exposure levels at sites with and without rain as measured 7 to 10 days after the Chernobyl accident in regions affected by the main fallout cloud.



Note: The exposure, E, is measured as a multiple of the natural background, assumed to be 0.01 millirems per hour, and is proportional to the distance, r, from Chernobyl, or $E = (6.9 \times 10^4)r^{-1.4}$

mains under investigation. Numerous countries and provinces have prepared detailed maps compiling measurements. At a national level, average and maximum depositions for cesium 137 and iodine 131 have been compiled by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD).[11] Independently, the U.S. Department of Energy has tabulated average depositions for all affected countries.[12] The data of the two efforts agree to within a factor of 2 for most countries, although in some cases (for example, Norway and Turkey) the discrepancies range to a factor of 5 to 10 (see Table 1 on this page).

Surprisingly, there is no distinct "break" between local dispersion and the distant radiation deposits (see Figure 2 on page 6): in general, the farther a country is from Chernobyl, the lower was its average deposition. Significant deviations from the trend are largely explained by the weather:[13] at a given distance, rainfall locations exhibited activities 15 to 20 times higher than dry locations. For this reason, a number of rainfall locations in Western Europe, for example, southern West Germany and central Austria, received exposures that were comparable to dry deposition within 100 to 200 kilometers from the accident, and some rainfall locations in Japan were equivalent to dry locations in Denmark. Wet deposition, further, has very sharp boundaries. Coping with localized hot spots was both a source of public confusion and a special challenge for risk managers.[14]

The ground concentration of the isotope cesium 137 in West Germany illustrates the nonuniformity of fallout deposition (see Figure 3 on page 8) and specifically illustrates the general fact indicated in Figure 2. The regions of highest deposition, in southern Bavaria, exceeded 40 kilobecquerels per square meter, whereas the regions with the lowest deposition, near Hamburg, had levels below 2 kilobecquerels per square meter.

The total activity released by the accident was about 10,000 times larger than the worst previous nuclear accident, at Windscale in the United Kingdom in 1957.[15] Although the release at Chernobyl was exceeded by the total release from atmospheric nuclear weapons testing during the period from 1945 to 1980 (by factors between 8 and 500 depending on the radionuclide), the locally deposited concentration of cesium 137 substantially exceeded the historic nuclear-weapons-testing fallout in countries such as the USSR, Poland, Austria, Sweden, Italy, and West Germany (see Table 1).

For all but the 31 individuals who died in the original explosion or during the fire fighting at the reactor, radiation exposure was insufficient to produce immediate (acute) health effects. In particular, 116,000 evacuees from within 30 kilometers of the plant received an average dose of 0.16 sieverts, or about 3 percent of the lethal dose.[16] For this reason the most far-reaching health consequence of the accident will be a relatively large number of delayed cancers.

TABLE 1

CESIUM-137 DEPOSITION IN COUNTRIES AFFECTED BY CHERNOBYL FALLOUT WITH A COMPARISON OF DEPOSITION FROM NUCLEAR WEAPONS TESTING IN SELECTED COUNTRIES

COUNTRY	AVERAGE DEPOSITION		MAXIMUM DEPOSITION	TOTAL DEPOSITION	NUCLEAR WEAPONS TESTING
	OECD	DOE	OECD	DOE	
	(kilobecquerels per square meter)			(10^{14} becquerels)	(kilobecquerels per square meter)
Albania		13		3.9	
Austria	23	39	60	11.0	5.2
Belgium	1.3	0.6	3	0.19	
Bulgaria		24		27.0	
Canada	0.04	0.025	0.065	2.5	
China		0.056		5.4	
Czechoslovakia		4.5		5.9	
Denmark	1.7	1.1	4.6	0.5	2.6
Finland		5.6		19.0	1.9
France	1.9	1.5	7.6	8.3	
Germany, East		5.2		5.8	
Germany, West	6.0	6.4	65	16.0	
Greece	5.3	3.3	28	4.4	
Hungary		8.3		7.9	
Ireland	5.0	3.5	22	2.5	
Israel		0.2		0.05	
Italy	6.5	6.3	~100	11.0	5.6
Japan	0.13	0.07	0.41	0.26	
Kuwait		0.05		0.01	
Luxembourg	4.0	1.5	7.3	0.04	
Netherlands	2.7	1.6	9.0	0.68	
Norway	11	2.8	~100	11.0	
Poland		29		92	
Rumania		27		67	
Spain	0.004	0	0.04	0	
Sweden	8.2	7.5	190	34	
Switzerland	8.0	4.8	41	2.0	
Turkey	0.08	2.3	0.09	18.0	
United Kingdom	1.4	1.8	20	4.4	4.1
United States	0.04	0.03		2.8	
Yugoslavia		23		61	

Note: The unit *kilobecquerel* refers to a rate of 1,000 nuclear decays per second.

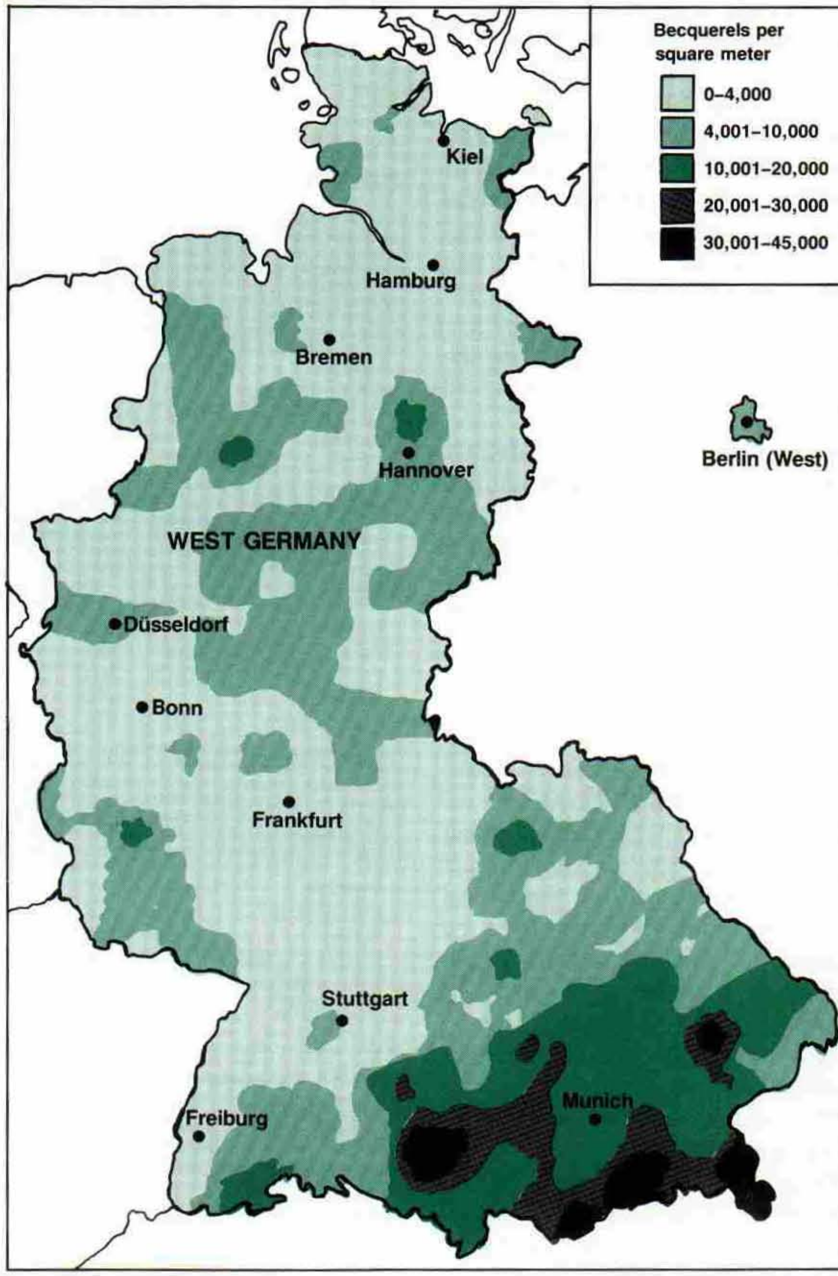
SOURCES: DOE data from U.S. Department of Energy, "Health and Environmental Consequences of the Chernobyl Nuclear Power Plant Accident," DOE/ER-0332 (National Technical Information Service, Springfield, Va., 1987); OECD and nuclear testing data from Nuclear Energy Agency, *The Radiological Impact of the Chernobyl Accident in OECD Countries* (Paris: Organization for Economic Cooperation and Development NEA, 1988).

Extensive efforts have been made to calculate this burden, and the details are reviewed elsewhere.[17] The calculations generally estimate the radiation dose for a population and, based on this, determine projected cancer fatalities. The first step requires evaluation of radiation exposures over each of several pathways, such as ingestion, inhalation, and external exposure from the passing cloud or ground deposits; the second step involves application of one or more dose conversion models in order to arrive at the number of projected cancer fatalities.

The U.S. Interlaboratory Task Force[18] and OECD[19] have reported radiation doses for 35 countries (see Table 2 on page 10). As with Table 1, the two studies agree to within a factor of 2 for most countries, although larger discrepancies exist in some cases. The results are expressed as the "collective dose" and the "average individual dose." The first allows estimation of the cancer burden for an entire population, while the second divides the collective dose by the national population size and thus permits comparison of the risk for an average individual. In both cases the dose is measured in sieverts, a unit that allows direct conversion to cancer risk via a suitable dose response model. For the collective dose, the size of the population is multiplied by the number of sieverts each individual receives (person-sieverts).

Conversion of dose to expected cancer fatalities is an inherently statistical concept. Very roughly, we can expect 1 excess delayed cancer fatality for each 50 to 100 person-sieverts. In Poland, for example, where the collective 50-year dose from the Chernobyl accident was about 150,000 person-sieverts, we can expect 1,500 to 3,000 additional cancer fatalities in the next 50 years. By the same logic, in the United States, for which the 50-year dose was about 1,000 person-sieverts, we can expect 10 to 20 additional cancer fatalities in the next 50 years. Some specialists would assign a larger range of error to these calculations;[20] for this reason the numbers derived here should be taken as illustrative only.

FIGURE 3. Cesium-137 ground deposition in West Germany from April 30 to May 5, 1986.



SOURCE: Bundesminister für Umwelt, *Tschernobyl und die Folgen—Ein Jahr danach*, Drucksache 11/755 (Bonn, F.R.G.: Deutscher Bundestag 11 Wahlperiode, 1987).

Based on the above logic, one may also derive an average individual's risk of dying of cancer because of exposure to the Chernobyl fallout. This is obtained by dividing the total expected cancer burden by the size of the population. For Poland this works out to an individual risk of 4 to 8 out of 100,000, whereas for the United States it implies an individual risk of 4 to 8 out of 100 million. These results for the number of expected cancer fatalities must be compared with an individual cancer risk of about 2 out of 10 from other causes (that is, about 1 individual in 5 succumbs to cancer). This indicates that,

Officials in some countries undertook screening efforts to identify radiation in food products and other portable entities such as vehicles, here in the vicinity of the Chernobyl plant. (Photo: Sovfoto)

relatively speaking, the effects of the Chernobyl accident are quite small for most individuals.

Nevertheless, because these small risks affect large populations, the cumulative burden involves a projected number of additional cancer fatalities as high as 28,000 worldwide over the next 50 years.[21] Of these, about half are expected to occur in the Soviet Union, and just about all the remainder in non-Soviet Europe. Of the 13,000 fatalities expected for non-Soviet Europe, about 4,000 are expected to occur in Western Europe. In viewing these "predictions," it should be clear that the expected fatalities will be statistically indistinguishable from cancer deaths produced via other mechanisms. This is because the predicted fatality rates are in all cases a very small fraction of the total.

In addition, many experts in radiation risk analysis suggest there may be as few as zero fatalities. This results from the fact that available dose-response coefficients are extrapolated from high-dose regions (Hiroshima survivors) to low-dose regions typical of Chernobyl. In this situation linear extrapolation is widely considered the most conservative assumption and leads to the result of 28,000 eventual Chernobyl fatalities. At the same time, the possible existence of a dose threshold below which there is no increase in the probability of cancer occurring is an optimistic assumption, which in the case of Chernobyl would imply that there may be no eventual cancer fatalities.

Public Attitudes after Chernobyl

Opinion polls to investigate the public attitude toward nuclear energy were conducted after the accident in almost every Western country. Not surprisingly, opposition to nuclear power increased in all countries. In spite of some recovery in recent months, opposition has in no case returned to pre-Chernobyl levels (see Figure 4 on page 11 for a representative summary of public opinion data just before, immediately after, and one year after the accident).[22]

Opposition to nuclear power from country to country was by no means uniform even before the Chernobyl accident; it ranged from a low of 28 percent in Greece to a high of 65 percent in the United Kingdom. In this respect the United States, with 43 percent opposed, was about average. Immediately after the accident, shifts in the level of opposition were substantial in some nations and quite small in others. For example, Finland, Yugoslavia, and Greece experienced increases in opposition of about 30 percentage points, whereas France and the United States recorded much more modest changes of 12 and 6 percentage points, respectively.

Observers of Eastern bloc countries have also detected a growing opposition to nuclear power, particularly in Poland, Hungary, Yugoslavia, and Czechoslovakia.[23] Data are available only for Yugoslavia, where three months after the accident the percentage of opponents of nuclear energy had increased from 42 to 78. One year after the accident, the number of opponents was still 24 percentage points higher than before the accident.[24]

Survey results suggest that public response was aggravated by poor risk communication.[25] Frequently, citizens were convinced that the government was not telling the truth (63 percent of the French population, for example). In Germany some citizens complained that the government did not give sufficient or adequate information, whereas others felt overwhelmed by the flood of information and would have preferred more consistent and understandable messages.[26]

Whereas these issues surely played some role, it is also interesting to ask whether the change in public opposition to nuclear power reflected the actual radiation exposure in individual countries. This possibility is suggested by the fact that the public was relatively well served by the media's reporting of radiation levels, which analysts considered to be to a large extent accurate and objective.[27]

To examine the relationship between radiation exposure and public opinion, Figure 5 (on page 41) shows the average individual 50-year whole body dose as a function of the change in public opposition to nuclear power from the period immediately before to that immediately

TABLE 2

ANTICIPATED RADIATION DOSES: COLLECTIVE 1ST- AND 50-YEAR WHOLE BODY DOSES, THYROID DOSES, AND INDIVIDUAL 50-YEAR WHOLE BODY DOSES

	COLLECTIVE 1ST-YEAR DOSE				COLLECTIVE	AVERAGE INDIVIDUAL
	TOTAL BODY		THYROID		50-YEAR DOSE	50-YEAR DOSE
	OECD	DOE	OECD	DOE	DOE	DOE
COUNTRY	(10^3 person-sieverts)					(millisieverts)
Albania		3.3		9	6.0	1.9
Austria	4.9	7.8	17	30	14	1.9
Belgium	0.4	0.44	3.1		1	0.09
Bulgaria		22		60	40	3.5
Canada	0.06	0.05	0.1	0.1	0.1	0.004
China		4.4		10	4	0.09
Czechoslovakia		5.6		20	10	0.67
Denmark	0.14	0.4	0.33	1	0.8	0.16
Finland	2.5	2.2	4.5	9	4	0.83
France	1.3	6.6	7.4	20	12	0.22
Germany, East		6.7		30	13	0.77
Germany, West	18	33	91	100	60	0.95
Greece	3.6	2.2	27	8	4	0.48
Hungary		6.7		20	13	1.2
Ireland	0.37	1.0	1.8	3.0	1.8	0.51
Israel		0.08		0.02	0.15	0.04
Italy	28	33	120	90	60	0.91
Japan	0.78	0.66	8.2	2	1.2	0.01
Luxembourg	0.05	0.04	0.16	0.1	0.08	0.21
Malta		0.22		0.2	0.4	0.91
Monaco		0.003		0.01	0.006	0.22
Netherlands	0.95	2.2	5.8	5.0	4.0	0.23
Norway	0.70	0.90	1.9	4.0	1.7	0.40
Poland		79		300	150	4.2
Portugal	0.06	0	0.15	0	0	0
Rumania		45		200	90	4.1
San Marino		0.01		0.04	0.02	0.91
Spain		0		0	0	0
Sweden	1.7	4.5	3.5	20	9.0	1.11
Switzerland	1.4	2.2	8.5	9.0	4.0	0.72
Turkey	0.83	8.8	5.3	30	17	0.35
United Kingdom	2.1	7.7	11	20	15	0.26
United States		0.55	3	1	1.1	0.004
USSR						
Evacuees					16	120
European					470	6.3
Yugoslavia		4.4		100	80	3.5

Notes: OECD dose figures represent a compilation of national reports, with correction for protective actions by each country. DOE dose figures are based on an independent compilation of data and a general dose model and do not contain correction for protective actions. Columns 1 and 2 represent 1st-year whole body doses due to ingestion, external exposure, and, in the case of the DOE values, inhalation. Columns 3 and 4 represent thyroid doses, which because of the short half-life of iodine 131, are all incurred in the first year. Column 5 represents the 50-year whole body dose, half from ingestion, half from external exposure, with less than 5 percent from inhalation. Column 6 represents average individual doses obtained by dividing column 5 by the affected population.

SOURCES: OECD dose figures from Nuclear Energy Agency, *The Radiological Impact of the Chernobyl Accident in OECD Countries* (Paris: Organization for Economic Cooperation and Development NEA, 1988). DOE dose figures are quoted in U.S. Department of Energy, "Health and Environmental Consequences of the Chernobyl Nuclear Power Plant Accident," DOE/ER-0332 (National Technical Information Service, Springfield, Va., 1987). Data for USSR are based on USSR State Committee on the Utilization of Atomic Energy, *The Accident at the Chernobyl' Nuclear Power Plant and Its Consequences*, A report compiled for the IAEA Experts' Meeting, 25–29 August 1986 (Vienna: International Atomic Energy Agency, 1986); USSR Ministry of Health, *Analysis of the Radiological Consequences of the Accident at the Chernobyl Nuclear Power Plant for the Population of the European Regions of the USSR*, Information Document A40/INF.DOC/9 (Copenhagen: World Health Organization, 1987).

after and one year after the Chernobyl accident. Whereas the data exhibit considerable scatter, it is evident that there is a positive relationship between the average dose in a country and the observed public opinion shift. For example, the United States, with essentially no exposure from Chernobyl, experienced a minimal increase in nuclear opposition, whereas nations such as Finland, Austria, and West Germany, which received relatively high radiation doses, experienced correspondingly larger increases in opposition. The positive relationship is highly significant in a statistical sense, so it is unlikely that the result obtained could be due to random fluctuations.

The high correlation at a national level between increased opposition to nuclear power and the actual average radiation dose following the Chernobyl accident indicates that, in spite of the confusion and the controversy about the seriousness of the threat, most citizens were capable of forming relatively accurate assessments, which were in part expressed in public opinion shifts. In saying this, it is not implied that people reacted directly to fallout levels but rather processed information from different sources and took into account expected biases. For example, one psychological study revealed that most Germans had confidence in the information of both the pro– and anti–nuclear power camps but felt that each source was emphasizing different aspects of the issue.[28]

Although by 1987 the initial postaccident increases in the level of opposition to nuclear power had fallen substantially in all countries (see Figure 4), the change in opposition from before the accident to 1987 continued to scale with the average radiation dose. Thus, at least for a year after the accident, the public has retained almost half of its increased opposition to nuclear power.

It is interesting to ask why the public "remembers" the Chernobyl accident in this way. It is equally interesting to ask why the public is willing to "forget" a portion of its increased opposition. An answer to these questions is based on analysis of public opinion shifts following the nuclear accident at Three Mile Island.[29] That analysis identified three dominant kinds of responses to a nuclear accident:

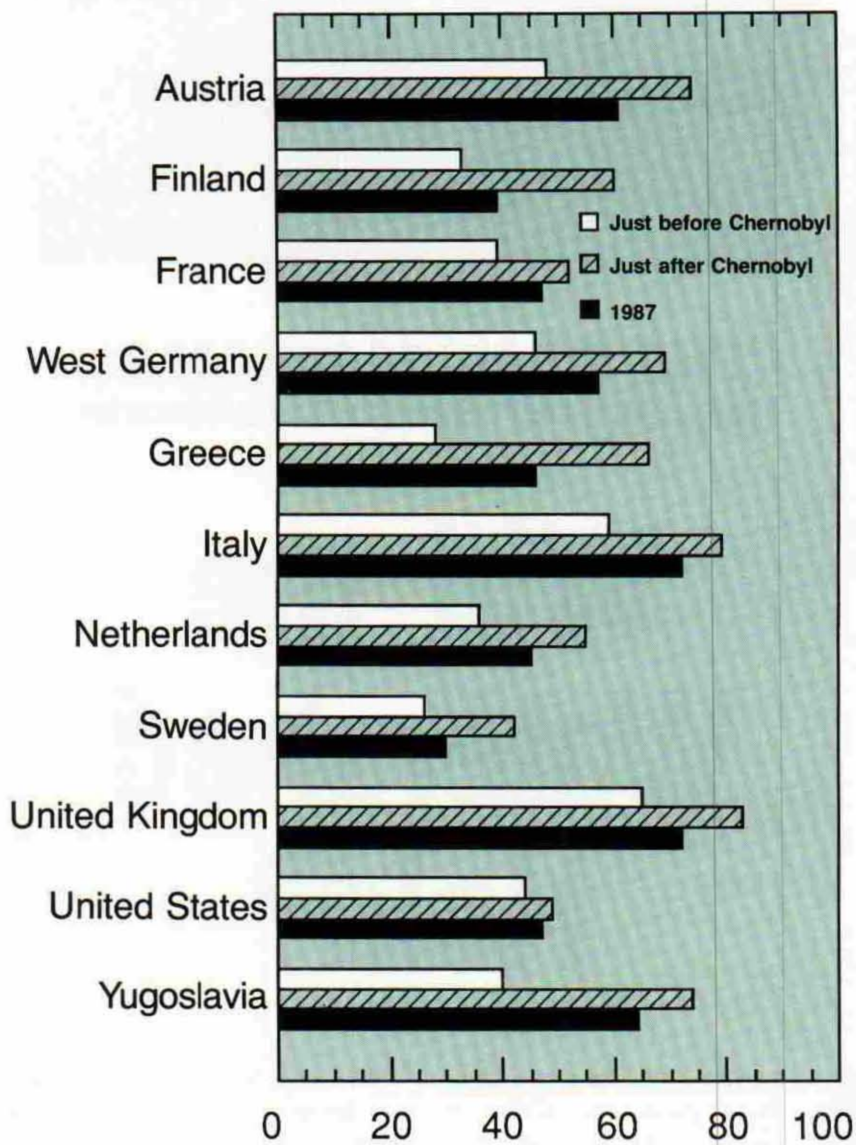
- Previously undecided individuals form a new attitude of opposition and become committed to it.
- Individuals with a previously positive attitude waver, become negative, and at least in some cases return to their original positive view if they do not feel personally affected by the accident.
- Previously negative individuals have their negative attitude reinforced and continue as negative.

In this model initial increases in opposition following the accident are driven by individuals of the first or second type whereas later declines in opposition are due only to individuals of the second type. If the Three Mile Island analysis is applicable to Chernobyl, one would have expected the largest initial increase in opposition in countries with a large fraction of uncommitted citizens, such as Greece and Yugoslavia, where the "don't know" response about opposition to nuclear power was as high as 30 percent before Chernobyl. And one would expect the largest return toward preaccident levels of opposition in countries where nuclear attitudes are well formed, such as the United States, Finland, West Germany, and the United Kingdom (for which the "don't know" response was generally below 5 percent before the accident). The data suggest that both conjectures are correct.

For individuals to return to their original opinions on the question of nuclear power requires, however, the emergence of evidence that convinces a group of formerly pro-nuclear individuals that its initial strong reaction in response to the Chernobyl accident may have been too extreme. Such evidence consists of information indicating that the accident was not as severe as originally anticipated, and/or that similar events would not recur or could not happen in one's native country. It is not clear, therefore, whether the severity of the Chernobyl disaster will allow the return to prior opinions even in nations with a mature nuclear debate (where the percentage of

(continued on page 40)

FIGURE 4. Percentage of respondents in 11 nations opposed to nuclear power.



Notes: Data have been compiled from surveys that asked respondents to indicate whether they "favor" or "oppose" the further development of nuclear power in their native countries or whether they "don't know." Data represent the percentage of the total survey sample in each country expressing explicit opposition to nuclear power.

SOURCES: H. Otway et al., "An Analysis of the Print Media in Europe Following the Chernobyl Accident: Report of the Joint Research Center of the Commission of the European Community (Ispra, Italy, 1987), 57–62; C. Flavin, "Chernobyl: The Political Fallout in Western Europe," *Forum for Applied Research and Public Policy*, Summer 1987, 16–28; P. Suhonen and H. Virtanen, "Public Reaction to the Chernobyl Nuclear Accident" (Research Institute for Social Sciences, University of Tampere, Finland, 1987); Heikki Raumolin, personal correspondence with Ortwin Renn, Perusvoima Oy, Helsinki, 3 September 1987; T. Roser, "The Social and Political Impact of Chernobyl in the Federal Republic of Germany," in Uranium Institut, ed., *Uranium and Nuclear Energy: 1987*, Proceedings of the 12th International Symposium, London, 2–4 September 1987 (London: Butterworth, 1988); "U.S. Fears and Doubts: A Newsweek Poll," *Newsweek* 12 May 1987; B. Verplanken, "Beliefs, Attitudes, and Intentions toward Nuclear Energy before and after Chernobyl in a Longitudinal Within-Subjects Design," *Environment and Behavior* (in press).

4. Dimas Arcia, technical director of the Panamanian Institute of Renewable Natural Resources (INRENARE), interview with author, Panama City, 2 October 1987.

5. F. H. Robinson, *A Report on the Panama Canal Rain Forest* (Balboa: Panama Canal Commission, 1985).

6. Ibid., 4.

7. Alvarado, note 3 above.

8. J. H. Diaz, "The Panama Canal Watershed: Truths and Myths" (Panama Canal Commission, Panama City).

9. Alvarado, note 3 above. Alvarado found that only 4.7 percent sedimentation has occurred in Madden Lake over the last 51 years. Most of the silt has accumulated over the last 25 years, when colonization by campesinos and cattlemen took place. Using a weighted calculation, a silt yield of 177.56 cubic feet per deforested acre per year is estimated. Given a 2,000-acre yearly deforestation rate, a loss of storage capacity of 18.4 percent should occur by 2010 to 2020 in a lake covering 19.4 square miles (the size of Madden Lake; Gatún Lake covers 163.38 square miles).

10. Republica de Panama-INRENARE, Resuelto No. 0013/87 (Panama City: INRENARE, 1987).

11. David Baerg, environmental/energy control officer, Panama Canal Commission, interview with author, Balboa, 30 September 1987.

12. Stanley Heckadon, interview with author, Panama City, 29 September 1987.

13. Felix Nuñez, president of Fundación PANAMA, interview with author, Panama City, 1 October 1987.

14. Frank Robinson, engineer with the Panama Canal Commission, interview with author, Balboa, 30 September 1987.

15. National Association for the Conservation of Nature (ANCON), *Estudio sobre la Conservación y Desarrollo de los Terrenos del Grupo Melo Dentro del Parque Nacional Chagres* (Panama City: ANCON, 1986).

16. Fernando Manfredo, deputy administrator of the Panama Canal Commission, interview with author, Panama City, 29 September 1987.

17. Letter from Alfred M. Beeton, chairman, Committee on Ecological Effects of a Sea Level Canal, Environmental Studies Board, U.S. National Academy of Sciences, to Frank Press, Office of Science and Technology Policy, Executive Office of the President, 28 September 1977.

18. Ibid.

19. Juan Hector Diaz, hydrologist with the Panama Canal Commission, interview with author, Balboa, 30 September 1987.

Chernobyl's Other Legacy

(continued from page 11)

uncommitted citizens was initially small). For nations in which large numbers of uncommitted citizens turned negative, it may, however, be predicted that much of the new opposition will persist.

Protective Actions

A broad range of protective actions to limit external and internal radiation exposure was undertaken in the countries affected by the fallout. Since no government was prepared for the transnational character of the accident, these actions involved a good deal of improvisation, inconsistency, and relatively little application of prior planning. The U.S. Interlaboratory Task Force[30] and OECD[31] have compiled a country-by-country survey of the protective actions taken (see Table 3 on this page). The actions described here were initiated within days of the accident in most countries, although in some cases there were significant delays in full implementation (see below).

The establishment of protective actions was beset by problems, such as failure to take optimal protective action for the population at risk and assuring the public that a clear and consistent management approach was being taken.[32] Confusion was heightened by inconsistent use of measurement units; politicization of the issue by interest groups (for example, environmentalists and the nuclear industry); the general public's fear of radiation; and overlapping responsibilities.[33] On the West German side of Lake Konstanz, for example, dairy cattle were kept off pastures and iodine levels in milk peaked at around 100 bec-

TABLE 3

PROTECTIVE ACTIONS TO CONTROL EXTERNAL AND INTERNAL RADIATION EXPOSURE

COUNTRY	Actions to limit external and inhalation exposure: Evacuation	Sheltering	Iodide Pills
Poland		x	x
USSR	x	x	x
Yugoslavia			x

COUNTRY	Actions to control the ingestive pathway: Milk or dairy product restrictions	Advice not to drink rainwater	Fresh Vegetables: Ban of sales	Fresh Vegetables: Advice not to eat	Fresh Vegetables: Advice to wash	Game & meat ban or restrictions	Food import ban
Austria	x	x	x	x	x		
Belgium	x				x		
Bulgaria	x		x	x			
Canada		x					x
Czechoslovakia	x						
Denmark					x		x
Finland	x						
France			x				
Germany, West	x	x	x			x	
Greece	x		x		x	x	
Hungary	x				x		
Israel							x
Italy	x	x	x	x			
Japan		x			x		
Netherlands	x	x	x		x		
Poland	x						
Rumania	x						
Spain		x					
Sweden	x	x		x	x	x	x
Switzerland	x	x		x	x	x	x
United Kingdom		x				x	x
United States							x
USSR	x		x				
Yugoslavia	x	x		x	x		

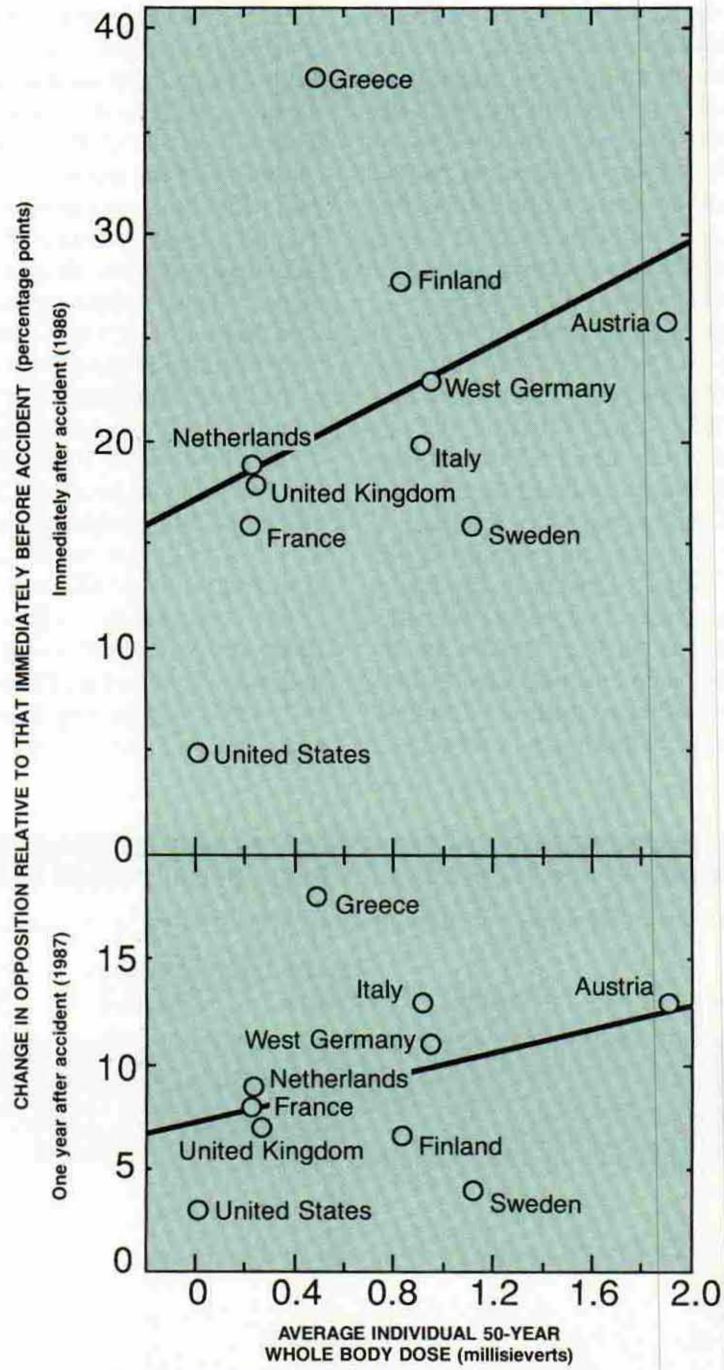
SOURCE: U.S. Department of Energy, "Health and Environmental Consequences of the Chernobyl Nuclear Power Plant Accident," DOE/ER-0332 (National Technical Information Service, Springfield, Va., 1987).

querels per liter, whereas on the Swiss side of the lake, cattle grazed on the fresh fallout and iodine levels in milk peaked at around 1,000 becquerels per liter.[34]

Some generic "defects" of the risk management undertaken by several European countries follow.

- There were significant national differences in setting allowable radionuclide concentrations in food (becquerels per liter or kilogram). This was because all authorities did not base their judgments on the same existing internationally agreed upon intervention levels specified in dose units (person-sieverts).[35]
- There was a general failure to integrate the application of national standards (through regulations specifying maximum levels of radiation) with the widely promulgated principle of achieving exposures "as low as reasonably achievable." Thus, local officials, noting that radiation levels lower than the national standards were achievable, took actions to specify such lower levels in place of the national standards. The public was thus confronted with two apparently conflicting standards.
- Nearly all countries demonstrated inexperience in designing and implementing monitoring programs for defining and controlling unusually high radiation levels brought about by rainfall (hot spots). For example, in southern West Germany safety assurances by the national government were in direct conflict with measurements reported by local officials.[36]
- The extent and practice of monitoring radiation in food resulted in significant confusion, particularly when international trade was involved. For example, some Western European countries placed a ban on food imports such as lettuce from Eastern Europe, even though they did not control their own food supplies.
- No country had in place adequate risk communication programs that defined the nature of radiation health effects. Citizens confronted with "becquerel/kilogram" levels in lettuce had no reliable way of translating this information into expected health effects.

FIGURE 5. Relationship between average individual radiation dose and the increase in opposition to nuclear power from the time immediately before to that immediately following and one year after the Chernobyl accident.



Immediately after the accident (top): The relationship indicates that the increase in opposition is directly proportional to dose. The relationship may be characterized by a correlation coefficient of 0.82. This indicates we can be 99 percent sure that the detected relationship is not due to random variation. **One year after the accident (bottom)**: As in the top graph, the relationship indicates that the increase in opposition remains proportional to the dose. The relationship is characterized by a correlation coefficient of 0.79, again indicating 99 percent certainty that the relationship is not random.

The question remains, How effective were the protective actions taken in various countries? According to the U.S. Interlaboratory Task Force, the question cannot usefully be answered because the pattern of protective actions (see Table 3) is insufficiently clear, and the effect of future actions cannot be ascertained.[37] At the same time, given that the most important radionuclides, iodine 131 and cesium 137, affect the food chain predominantly during the first year, one should expect dose savings achieved through protective actions on the food chains to be calculable.

Based on this approach, the Nuclear Energy Agency of OECD[38] has asked member countries to estimate the first-year "dose savings," that is, the percentage of the potential first-year dose averted through protective actions (see Table 4 on this page). It is clear that collective first-year dose savings varied widely, from 50 percent in the case of Austria to near zero in the case of France. However, as noted by OECD, the different estimation methods used by individual countries make the results subject to errors by as much as a factor of 3.

Uncertainties notwithstanding, are the variations in dose savings reflections of the intensity of the fallout and thus proportional to the extent of the threat? To answer this question, the mean anticipated 50-year whole body dose (Table 2, column 6) is compared with the percentage of average dose savings achieved in the first year (Table 4, column 1) for the United States and 13 Western European countries (see top graph of Figure 6 on page 43). There is evidently a strong relationship between dose and dose savings, suggesting that, despite the complexity of the protective action response, most Western European countries reacted in rough proportion to the exent of the threat. At the same time, the near total lack of dose savings in countries such as France, the United Kingdom, and Switzerland is notable. This may be due to the determination by authorities that expected doses would not exceed protective action guidelines.

The collected data reflect only national averages for both dose and dose reductions. Additional studies are needed to relate the regional dispersion of radionuclides with the regional effects of protective actions. Anecdotal evidence collected in Germany[39] and in France, Italy, and the United Kingdom[40] suggests that the dose reduction measures taken for local hot spots were often insufficient. For example, no special measures were taken to protect the milk supply in the Alpine regions of France and Switzerland where the fallout was high.

In order to get a better understanding of the scatter in the top graph of Figure 6, the relationship between dose savings and the commitment of a country to nuclear power, as measured by the share of its electricity generated by nuclear power, was investigated for 13 countries (see middle graph). The extremes of this variable suggest an inverse relationship with dose savings: Austria, which is dismantling its only nuclear reactor, had the highest dose savings, whereas France and Belgium, with nuclear power contributing 70 percent of each country's electricity, had dose savings of near zero. Even though the relationship is not a strong one, it indicates the possibility that countries committed to nuclear power were less active in averting exposure of their citizens through pro-

TABLE 4

ESTIMATES OF FIRST-YEAR WHOLE BODY DOSE SAVINGS FROM PROTECTIVE ACTIONS (percent)

	COLLECTIVE DOSE SAVING				INDIVIDUAL DOSE SAVING FOR THE CRITICAL GROUP[a]		
COUNTRY	TOTAL	INFANTS	CHILDREN	ADULTS	INFANTS	CHILDREN	ADULTS
Austria	50	53	50	50	80	72	64
Belgium	very small				—	—	—
Finland	7.2	12	11	6.3	16	2.1	5.0
France	very small				—	—	—
Germany, West	30[b]	—	—	—	~50	~50	—
Greece	23	25	17	24	25	17	23
Italy[c]	18	53	33	15	36	27	10
Luxembourg	7.5	17	13	6.6	12	13	6.9
Netherlands	15	43	23	12	36	23	14
Norway	32	29	28	33	33	15	19
Sweden	15	0	3	17	0	1.9	2.7
Switzerland	1	50	0	0	38	0	0
Turkey	12	0	18	11	0	37	9
United Kingdom	1	<1	1	1	14	19	23

Notes: Only countries that adopted protective measures are indicated. Estimates made by different national bodies may differ by as much as a factor of 3.

[a]The critical group was defined either as having enhanced radiation sensitivity (infants, children) or as experiencing especially high exposure brought on by localized radiation hot spots (adults). The radiation standard applied by different countries differed, and the results listed for critical groups are subject to substantial uncertainty.

[b]Overall estimate

[c]Average value of estimate made by two different national bodies

SOURCE: Nuclear Energy Agency, *The Radiological Impact of the Chernobyl Accident in OECD Countries* (Paris: Organization for Economic Cooperation and Development NEA, 1988).

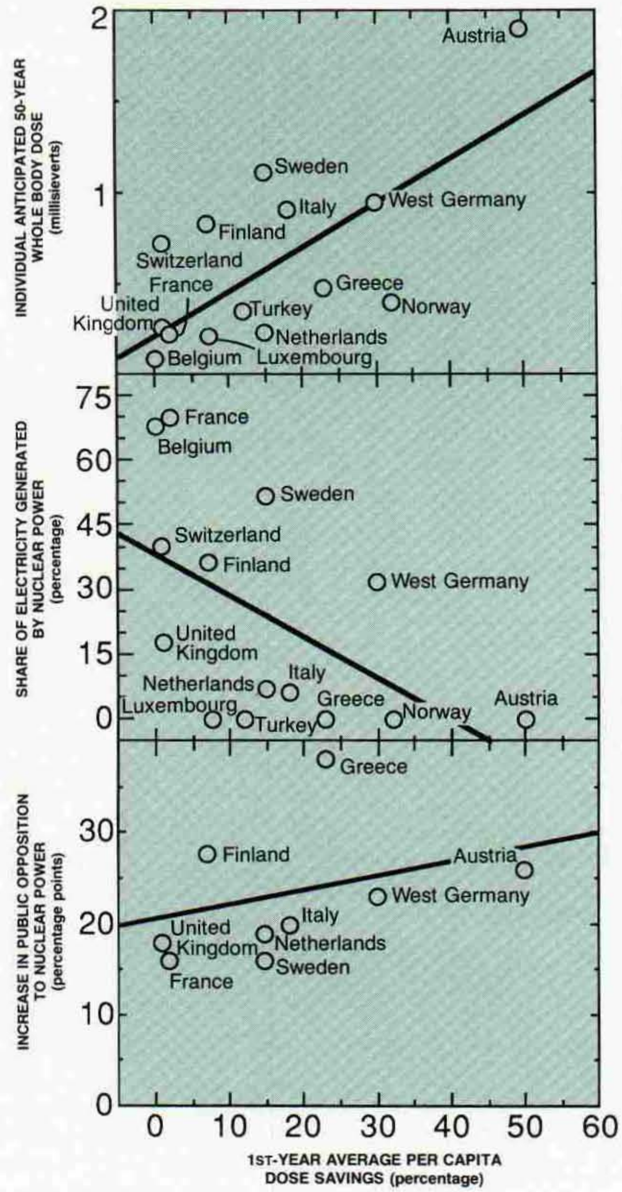
tective measures. This is surprising, since the existence of domestic nuclear power might reasonably be supposed to prepare a country for coping with the consequences of a nuclear accident. A plausible explanation in some countries (France, for example) is that authorities did not want to alarm citizens with actions that might increase the perception of danger with regard to nuclear power plants.

As another approach to understanding the variation of the average individual dose savings, its relation to the increase in public opposition to nuclear power immediately following Chernobyl was investigated (see bottom graph). The increase in public opposition is strongly related to the dose savings accomplished, a result that might be explained in terms of four alternative hypotheses:

- The increase in public opposition was triggered by an accurate perception of high-whole-body-dose levels, which, according to the top graph, are themselves related to dose savings.
- The increase in public opposition was an independent factor that produced substantial protective action.
- The increase in public opposition was triggered by vigorous government action to publicize the accident and to introduce protective actions.
- The correlation between increased public opposition and dose savings was affected by a combination of the above factors.

Based on the relationships exhibited in all three graphs of Figure 6, it can be concluded that the whole body dose, the level of commitment to nuclear power, and the increase in public opposition are all significantly related to the level of protective action on a national level. Unfortunately, without additional information, levels of relative importance of each of the factors cannot be assigned. Additional statistical analysis suggests, however, that commitment to nuclear power was not itself an independent factor but was already contained in the variation of the other two. Whereas the causal roots of these relations are not clear, the protective action

FIGURE 6. Relationship between estimated radiation dose savings and individual anticipated 50-year whole body dose, share of electricity from nuclear power, and increase in public opposition to nuclear power for Western European countries.



The relationship between the anticipated 50-year whole body dose per individual (**top**) and the per capita dose savings in the first year indicates that the average dose savings increased in proportion to the whole body dose. The relationship is characterized by a correlation coefficient of 0.70, indicating a 99 percent chance that the observed relation is not random. As the share of a country's electricity produced by nuclear power increases (**middle**), the average per capita dose savings in the first year decreases. In this case the correlation coefficient is only 0.36, indicating a relatively weak relationship (that is, there is only an 80 percent chance that the result is not random). The relationship between the increase in public opposition to nuclear power immediately after the accident (**bottom**) and the average per capita dose savings in the first year indicates that dose savings increased with increases in the extent of public opposition to nuclear power. The correlation coefficient of 0.48 indicates a 91 percent chance that the observed relationship is not random.

response appears rational, suggesting that the widely expressed concern regarding lack of preparedness and risk communication failures should be seen as a criticism of the adequacy of the response, not of its rationality.

New Insights and Challenges

The accident at Chernobyl not only left its mark in the form of radioactive fallout in most European countries, it also had a lasting impact on emergency management, regulatory legislation, and public opinion. The analysis of projected whole body dose, dose savings, protective action, and public responses has revealed some interesting results as follows:

- The Chernobyl accident produced a highly variable pattern of fallout, with significant hot spots associated with local rainfall. These hot spots were a part of a broad trend reflecting a uniform decrease in fallout with distance from the accident site (see Figure 2).
- Although the number of immediate fatalities was surprisingly small, over the next 50 years there may be up to 28,000 fatalities worldwide from delayed cancers, about half of the fatalities in the Soviet Union and half in non-Soviet Europe. Despite the magnitude of these consequences, they represent less than 0.02 percent of the total expected cancer fatalities for most locations. Fewer than 20 additional deaths are expected in the United States.
- The transnational character of the fallout, and in particular the occurrence of localized hot spots, took European nations by surprise. Most nations were forced to improvise management efforts. Previous plans for protective actions, in particular for the ingestive pathway, were inconsistent and/or insufficient.
- The public response, measured in terms of increased opposition toward nuclear energy, was directly proportional to the average 50-year whole body radiation dose, suggesting there may be a connection between exposure and the change in public opposition to nuclear power.

CHERNOBYL AND THE U.S. MORTALITY RATE

Recently, Jay Gould, a statistician who served on the scientific advisory board of the U.S. Environmental Protection Agency during the Carter administration and is currently a fellow at the Institute for Policy Studies in Washington, D.C., noted that, compared with previous years, the raw U.S. mortality rate in summer 1986 jumped by 3 percent, amounting to 20,000 to 40,000 more deaths than usual. According to Gould, the observed change in mortality may be a result of the Chernobyl accident. "We regard this as merely a hypothesis," Gould told the *Wall Street Journal* on February 8, 1988, "and hope that someone can explain it short of Chernobyl."

That Gould's hypothesis should be correct seems unlikely for several reasons. Perhaps the most obvious is that nearly all evidence has it that the health effects of radiation are delayed, often by 5 to 30 years. In addition, the average individual U.S. whole body dose in the year following the Chernobyl accident averaged 4×10^{-6} sieverts (see Table 2 on page 10), or approximately one one-thousandth of the natural background. If this increment in exposure is capable of producing a 3 percent increase in the mortality rate, it would seem to follow that the natural background itself should be sufficient to kill everyone in the United States—at least if the effect is proportional to dose, as has been widely demonstrated in radiation biology.

Beyond this, Gould's hypothesis would imply that mortality effects in Europe should be greater by a factor of 100 to 1,000, since in Europe the exposure to radiation was that much greater. This means that West Germany, with 200 times the mean radiation exposure as that of the United States and with about one-fourth of the population, should have experienced 50 times the U.S. number of excess deaths in the summer of 1986, or 1 million to 2 million excess fatalities. Since West Germany has on the order of 500,000 deaths per year, this implies that in West Germany the mortality during summer 1986 would have been at 6 to 12 times the normal rate. And for southern regions hit by heavy rainfall, the mortality rate should have jumped by a factor of 50 to 100, which is close to saying that everyone in the south should have died.

Ernest J. Sternglass, professor emeritus of radiation physics at the University of Pittsburgh, attempts to circumvent this absurd result by positing that the U.S. mortality increase was triggered by internal doses of isotopes from the fallout like iodine 131, rather than by external gamma doses, and that the usual dose conversion coefficients do not apply. Unfortunately this won't wash, since in Europe the iodine-131 dose was proportionally even higher than in the United States.

Perhaps most significantly, Gould's claims violate one of the first rules of good epidemiology: there must be an adequate control group that has the same health and economic history as the presumed victims but lacks the exposure of the latter.

So what is going on? Why the observed increase in mortality? This is a worthwhile question that at this stage might involve any number of causitive factors. At this writing we must simply say we don't know.

Nevertheless, it is useful to recall a similar episode in the 1960s in which Sternglass claimed that a big jump in the infant mortality rate in New York City was caused by fallout from atmospheric hydrogen bomb tests. Sternglass, like Gould, observed a temporal conjunction between the tests and New York's infant mortality rate. He even performed a calculation much like the one for West Germany above, from which he predicted the "death of all children" in a major national magazine.

It was left to John Gofman, currently emeritus professor of medical physics at the University of California in Berkeley, to point out that the infant mortality increase had a more mundane explanation: New York had absorbed many poor people from rural regions; the recent arrivals brought with them a lower standard of living and an associated higher infant mortality rate that was more than sufficient to produce the change attributed to H-bomb tests.

In Gould's case it might have been wiser to look for such changes before jumping to his most implausible Chernobyl hypothesis. One good direction to look is the demographics of the U.S. population, which is rapidly aging and will experience higher mortality in the future in any case.

—C. H.

• For countries with a low percentage of uncommitted or "don't know" attitudes toward nuclear power before the Chernobyl accident, increases in opposition following the accident were largely temporary. By contrast, in countries with a high percentage of uncommitted citizens, the initial increase in opposition was large and relatively permanent.

• In spite of the confusion and inconsistencies in management responses, the average dose reduction (dose savings) accomplished by each country was highly correlated with exposure, that is, the average potential whole body dose. By whatever mechanism this was achieved, it leads one to designate the response as "rational." This observation is, however, only true with respect to the average radiation level; the effectiveness of the management performance with respect to reducing the risk in localized hot spots could not be investigated.

• An additional factor related to dose reduction was the observed increase in opposition to nuclear power as measured in public opinion surveys.

The Chernobyl accident thus provided new insights about public opinion response to public policy and also new challenges for risk management. The mechanisms driving the relationships described here are so far unclear, and this analysis must be seen as the beginning of further research on public opinion and policy issues. The analysis, furthermore, is valid only on an aggregate or average level, and individuals may react differently. In particular, it seems the actions taken by individuals to protect themselves against radiation hazards were less related to actual levels of contamination than to other considerations, such as the extent of trust placed in government.[41]

Although most countries seem to have coped well with the severity of the fallout situation on an average level, more refined analyses about the adequacy of the management response on the local and regional level should be conducted. In addition, significant dispersion of fallout across national borders requires new provisions and ideas for national and local radiation monitoring, food control, and anticipatory communication with the public about adequate protective actions. A host of new laws and regulations addresses these issues, but that is beyond the scope of this article.

ACKNOWLEDGMENT

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NOTES

1. C. Hohenemser, M. Deicher, A. Ernst, J. Hofsäss, G. Lindner, and E. Recknagel, "Chernobyl: An Early Report," *Environment*, June 1986.

2. USSR State Committee on the Utilization of Atomic Energy, *The Accident at the Chernobyl' Nuclear Power Plant and Its Consequences*, A report compiled for the IAEA Experts' Meeting, 25–29 August 1986 (Vienna: International Atomic Energy Agency, 1986); International Safety Advisory Group, "Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident," GC(SPL.I)/3 (IAEA, Vienna, 1986); U.S. Nuclear Regulatory Agency, *Report on the Accident at the Chernobyl Nuclear Power Station*, NUREG 1250 (Washington, D.C.: U.S. Government Printing Office, 1987); U.S. Department of Energy, "Health and Environmental Consequences of the Chernobyl Nuclear Power Plant Accident," DOE/ER-0332 (National Technical Information Service, Springfield, Va., 1987); U.K. Atomic Energy Authority, *The Chernobyl Accident and Its Consequences* (London: H. M. Stationery Office, 1987); Nuclear Energy Agency, "Chernobyl and the Safety of Nuclear Reactors in OECD Countries: Report of the NEA Group of Experts" (Paris: Organization for Economic Cooperation and Development NEA, 1987); NEA, *The Radiological Impact of the Chernobyl Accident in OECD Countries* (Paris: OECD NEA, 1988). A detailed review of this material will appear in C. Hohenemser, "The Accident at Chernobyl: Health and Environmental Consequences and the Implications for Risk Management," *Annual Review of Energy* (in press).

3. H. Otway, P. Haastrup, W. Cannell, G. Gianitsopoulos, and M. Paruccini, "An Analysis of the Print Media in Europe Following the Chernobyl Accident: Report of the Joint Research Center of the Commission of the European Community (Ispra, Italy, 1987), 57–62; C. Flavin, "Chernobyl: The Political Fallout in Western Europe," *Forum for Applied Research and Public Policy*, Summer 1987, 16–28.

4. USSR State Committee, note 2 above. For a review of the committee's report see H. W. Lewis, "Report on Reports," *Environment*, November 1986.

5. Hohenemser et al., note 1 above.

6. H. W. Lewis et al., "Report to the American Physical Society by the Study Group on Light Water Reactor Safety," *Reviews of Modern Physics*, (supp. 1), 47(1975):S1–S123.

7. USSR State Committee, note 2 above.

8. DOE, note 2 above.

9. Hohenemser, note 2 above.

10. D. A. Powers, T. S. Kress, and M. W. Jankowski, "The Chernobyl Source Term," *Nuclear Safety*, 28, no. 1(1987):10–28.

11. NEA, *The Radiological Impact*, note 2 above.

12. DOE, note 2 above.

13. Hohenemser et al., note 1 above.

14. Hohenemser, note 2 above; M. Deicher, A. Ernst, H. Hofsäss, C. Hohenemser, G. Lindner, and E. Recknagel, "The Accident at Chernobyl: Issues in Local Risk Management, " in International Institute for Applied Systems Analysis, ed., *Proceedings of the IIASA Conference on Chernobyl* (Laxenburg, Austria: IIASA, in press).

15. M. J. Crick and G. S. Linsley, *An Assessment of the Radiological Impact of the Windscale Reactor Fire, October 1957*, Report NRPB-R135 (Chilton, Didcot, Oxon, U.K.: National Radiological Protection Board, 1982). See *International Journal of Radiation Biology* 46 (1982): 479–506.

16. DOE, note 2 above.

17. Hohenemser, note 2 above.

18. DOE, note 2 above.

19. NEA, *The Radiological Impact*, note 2 above.

20. F. von Hippel and T. B. Cochran, "Chernobyl: Early Thoughts about the Long-Term Health Consequences," *Bulletin of the Atomic Scientists*, September 1986.

21. DOE, note 2 above.

22. Otway et al. and Flavin, note 3 above; P. Suhonen and H. Virtanen, "Public Reaction to the Chernobyl Nuclear Accident" (Research Institute for Social Sciences, University of Tampere, Finland, 1987); Heikki Raumolin, Perusvoima Oy, personal correspondence with Ortwin Renn, Helsinki, 3 September 1987); T. Roser, "The Social and Political Impact of Chernobyl in the Federal Republic of Germany," in Uranium Institut, ed., *Uranium and Nuclear Energy: 1987*, Proceedings of the 12th International Symposium, London, 2–4 September 1987 (London: Butterworth, 1988); "U.S. Fears and Doubts: A Newsweek Poll," *Newsweek*, 12 May 1987; B. Verplanken, "Beliefs, Attitudes, and Intentions toward Nuclear Energy before and after Chernobyl in a Longitudinal Within-Subjects Design," *Environment and Behavior* (in press).

23. "Reactions to Chernobyl in Europe," *Washington Post*, 5 May 1986.

24. Flavin, note 3 above.

25. Otway et al., note 3 above.

26. H. P. Peters, G. Albrecht, L. Hennen, and H. U. Stegelmann, "Die Reaktionen der Bevölkerung auf die Ereignisse in Tschernobyl: Ergebnisse einer Befragunge," Report of the Nuclear Research Center (Jülich, Jül-Spez-400, 1987).

27. Otway et al., note 3 above; S. M. Friedman, C. M. Gorney, and B. P. Egolf, "Reporting on Radiation: A Content Analysis of Chernobyl Coverage," *Communications* 37, no. 3(1987):58–67.

28. Peters et al., note 26 above.

29. O. Renn, *Risikowahrnehmung der Kernenergie* (Frankfurt and New York: Campus, 1984), 294–99; O. Renn, "Public Responses to Chernobyl: Lessons for Risk Management and Communication," in Uranium Institut, ed., note 22 above.

30. DOE, note 2 above.

31. NEA, *The Radiological Impact*, note 2 above.

32. Otway et al., note 3 above; Deicher et al., note 14 above.

33. Otway et al. and Flavin, note 3 above; Roser, note 22 above; W. Wallmann, "Chernobyl's Impact in West Germany," *Forum for Applied Research and Public Policy*, Summer 1987, 13–15.

34. Hohenemser et al., note 1 above.

35. Hohenemser, note 2 above.

36. Hohenemser et al., note 1 above.

37. DOE, note 2 above.

38. NEA, *The Radiological Impact*, note 2 above.

39. Hohenemser, note 1 above; Deicher et al., note 14 above.

40. Otway et al., note 3 above.

41. Ibid.