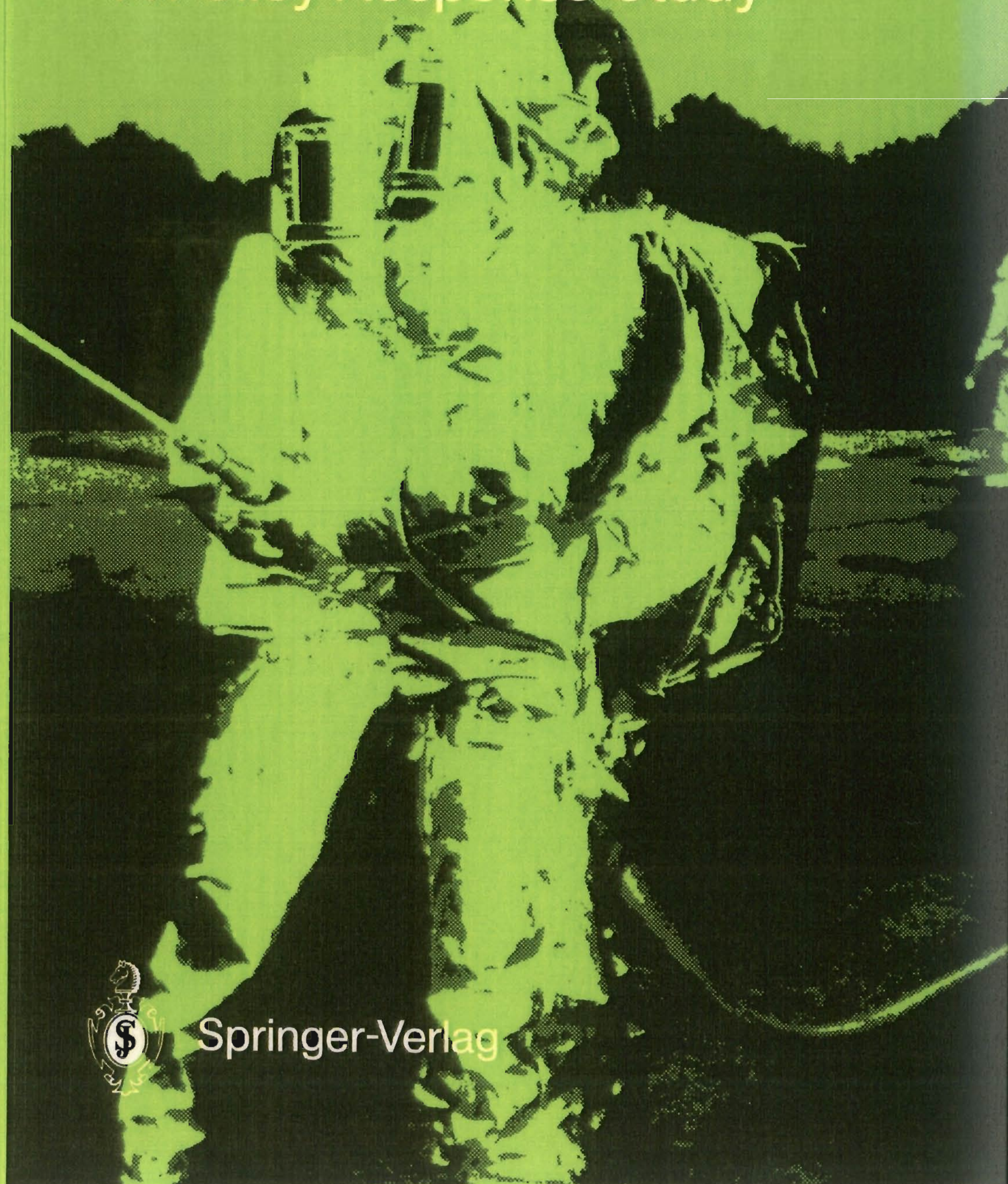
Boris Segerståhl (Ed.)

Chernobyl

A Policy Response Study



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Chernobyl:

A Policy Response Study

With 4 Figures

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Series Preface

This series is dedicated to serving the growing community of scholars and practitioners concerned with the principles and applications of environmental management. Each volume is a thorough treatment of a specific topic of importance for proper management practices. A fundamental objective of these books is to help the reader discern and implement man's stewardship of our environment and the world's renewable resources. For we must strive to understand the relationship between man and nature, act to bring harmony to it, and nurture an environment that is both stable and productive.

These objectives have often eluded us because the pursuit of other individual and societal goals has diverted us from a course of living in balance with the environment. At times, therefore, the environmental manager may have to exert restrictive control, which is usually best applied to man, not nature. Attempts to alter or harness nature have often failed or backfired, as exemplified by the results of imprudent use of herbicides, fertilizers, water, and other agents.

Each book in this series will shed light on the fundamental and applied aspects of environmental management. It is hoped that each will help solve a practical and serious environmental problem.

Robert S. DeSanto
East Lyme, Connecticut

Preface

Research on risk issues has a long tradition at IIASA. In 1986 a decision was made by the IIASA Council to strengthen the Institute's research on technological risk. Within this framework an international group of scientists working in the risk field met several times to discuss the nontechnological impacts of the Chernobyl accident. Specific issues discussed were the way in which authorities react, the role and behavior of the media system, the decision-making structures, and the way in which international coordination systems function. Out of these discussions emerged a set of papers dealing with societal responses to the accident. It was decided to collect these papers into a volume dealing with what we call the policy responses that emerged in different European countries.

Boris Segerståhl
Director
Research Institute of Northern Finland

Contents

THE INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

is a nongovernmental research institution, bringing together scientists from around the world to work on problems of common concern. Situated in Laxenburg, Austria, IIASA was founded in October 1972 by the academies of science and equivalent organizations of twelve countries. Its founders gave IIASA a unique position outside national, disciplinary, and institutional boundaries so that it might take the broadest possible view in pursuing its objectives:

To promote international cooperation in solving problems arising from social, economic, technological, and environmental change

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To inform policy advisors and decision makers about the potential application of the Institute's work to such problems

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of Soviet Socialist Republics

United States of America
The American Academy of Arts and
Sciences

Chapter 1

Introduction

Boris Segerståhl
Research Institute of Northern Finland
Oulu, Finland

Valery Legasov is the man who was in charge of damage control and reconstruction after the accident at Chernobyl. He is one of the victims of this accident. He committed suicide one year after the accident.

In his so-called "Legasov Memoirs," published in *Pravda* on 20 May 1987, Academician Legasov writes, "Unfortunately we do not have enough books about Chernobyl, all the lessons of what happened have not been fully analyzed." This statement holds true even today, several years after the accident. It is clear that a unique and traumatic event like the accident at Chernobyl will never be fully understood and described. Most of the reporting after the accident concentrated on questions related to nuclear engineering and power-plant safety. In addition, a lot of attention was paid to the health effects of radioactive contamination. What took place in society as a whole was not recorded with much detail. This omission cannot be corrected. Societal events cannot be recollected with total recall after they have taken place. We try, however, in this book to give a modest account of what happened in Western Europe during the time after Chernobyl.

In the "Legasov Memoirs" Chernobyl is compared to significant historic events, like the destruction of Pompeii. Today this comparison is still possible but not very likely. As time passes, Chernobyl will be viewed in the West as one accident of many; although it had, when it occurred, an enormous effect on everyday life in many countries. The events that took place in Western Europe proved, in a unique way, that well-organized societies could cope with previously unknown and only partly understood crises. For this reason, it is important to put on record what happened: what was done right and what was not.

The Chernobyl accident led to simultaneous mobilization of many societal defense mechanisms on a scale and at a speed that was unprecedented in peacetime Europe. As a test of Europe's ability to function as a unified continent, the result is mixed. In certain areas everything went smoothly, e.g., exchange of information between officials. In other areas – notably international food trade – the accident led to inconsistent or selfish actions, including trade constraints and subjective setting of intervention levels without foundation in scientific knowledge.

The whole pattern of reactions and responses to Chernobyl is society's policy response to the accident. A policy response is the reaction by society as a whole to an incident or accident that cannot be confined to a narrow sector or closed region, but which has a broad and often uncontrollable national or international scope. Policy responses have three rational goals:

(1) Implement measures to minimize exposure to radiation.
(2) Limit economic impact of the accident.
(3) Revise procedures to avoid future similar accidents and improve response mechanisms if an accident occurs

This list gives too simple a view of reality. In a real situation, like Europe after Chernobyl, there is a lot of confusion with many stakeholders and conflicting interests. This makes consistent decision making extremely difficult. To this confusion was added the problems caused by a lack of information. During the first days and weeks after the accident nobody knew exactly what had happened. Predictions based on what was known were more a matter of guessing than of knowing, as there was a complete lack of experience.

A nuclear power plant is in one fundamental way different from other complex technological systems. Most nonnuclear systems can, as a consequence of an accident, cause damages which are measurable on a fairly continuous scale from minor leaks to catastrophic disasters like the one in Bhopal. In the case of nuclear installations, there is a discontinuity on this scale. The discontinuity is caused by the difference between accidents which do not cause releases of radionuclides and accidents which do. To a certain extent, this discontinuity is perceived and not technical. A small release of slightly contaminated water can cause more problems for the plant's management than a substantial fire which did not lead to any releases even if it had the potential to cause a major accident.

This discontinuity in the level of awareness has lead to the incorrect assumption that nuclear power plants are completely safe and operate without even minor accidents until the occasional big accidents occur. This situation is partly caused by the industry itself. There is a history of secrecy and unwillingness to disclose information about "minor" accidents. These minor accidents are, however, fairly common. In West Germany at least 305 incidents affecting the safety of nuclear power plants occurred in 1987. Eleven were serious enough to be considered worthy of "rapid attention" (Charles, 1988). In the USA there were nearly 3,000 plant mishaps and 764 emergency shutdowns in 1985, up 28% from 1984 (Flavin, 1987). Another source states that "between 1971 and August 1984 two significant and 149 potentially significant mishaps occurred in 14 industrial nations outside the two superpowers" (Ramberg, 1986). These facts are mentioned only to point out that nuclear installations are as prone to malfunction as all other technological systems. In addition fairly good statistics are available, although the industry itself is extremely reluctant to discuss these aspects of their activities.

The probable reason for the nuclear industry's unwillingness to release information on incidents is that it is assumed that this information would be used in debates as arguments against nuclear power. This approach to risk communication has backfired, as the general public has seen shattering evidence of the fact that there is no fundamental difference between a nuclear power plant and other human-built systems. They are all, to a varying extent, unreliable; when they fail they sometimes cause damage to property and lives.

Every accident is followed by a debate concerning its cause. In most cases (both nuclear and nonnuclear accidents) the main conclusion seems to be that the accident was caused by "human error." It is common practice to distinguish between system failures and human errors. Whether this is a fruitful way to approach the question is unclear. For example, one report on the Windscale accident states that "because of the inadequate instrumentation, the operator mistakenly thought ..." (Dunster, 1988, p. 147). In another article it is reported that "the accident began when a faulty maneuver by an operator ..." (Dickson, 1988, p. 556). The first version puts the primary blame on the technical system, while the second one places it on the operator.

Davies (1986) writes:

> There is nothing, when measured in terms of a strict algebra of death, damages, and injuries, that is particularly special about nuclear power. Many other potentially hazardous installations operate worldwide, and some, in their turn, cause serious accidents.

This statement is open to a lot of criticism. There might be certain qualitative and quantitative aspects of the "algebra" that are very special in the case of nuclear power. We are not going to discuss these comparative risk assessment problems here. One point is, however, quite clear: public opinion does not completely agree with the statement quoted above.

1.1 Other Accidents

Chernobyl was not the first nuclear power plant to suffer core damage. The core at Three Mile Island (TMI) Unit 2 was badly damaged during its accident in 1979. The release of radioactive material from TMI was, however, very small. The accident at Windscale was never fully documented publicly. It is therefore difficult to say what similarities there might be between this accident and Chernobyl. There are, however, two important reasons for stating that Chernobyl is unique. First, large populations were for the first time not only frightened but also contaminated by radioactive fallout. Second, the biological impact through contamination spread over a whole continent, directly involving many countries and international organizations.

One problem with reporting on nuclear accidents is that it is difficult to get reliable and accurate information. In some cases there is almost no information available, while in others the volume of inaccurate and contradictory information is so huge that one could not describe accurately what really happened.

Another important fact is that this information refers mainly to commercial installations. It is difficult to obtain information on experimental reactors or military nuclear installations. John Horan of the International Atomic Energy Agency said during a workshop in 1980: "I have identified six major accidents in the past 27 years of our industry. Only two involved commercial nuclear power plants" (Lathrop, 1981, p. 14). He did not identify the other four cases. They could be reprocessing plants, experimental reactors, or military installations. The obvious exception to the general principle of secrecy in the military sector is in cases of accidents in submarines and other naval vehicles. These cases hit the headlines, not because of an anomaly in the information policy of the military establishment but because of the fact that these accidents are so obvious.

In addition to the "three big ones" (Windscale, Three Mile Island, and Chernobyl), a long list of serious accidents in nuclear installations can be compiled. A few of these are discussed below.

The accident that occurred at the Windscale Works at Sellafield, Cumberland, in October 1957, was the result of a deliberate release of Wigner energy from the graphite moderator.[1] Because of inadequate instrumentation, the operators thought the core was cooling without releasing all the energy. A second period of heating overheated several fuel channels leading to a graphite fire that involved some 150 channels of fuel. The fire was finally extinguished by flooding the pile with large volumes of water. Flooding was used despite the warning that it might ignite the whole core (Dickson, 1989).

The Windscale accident was the first major nuclear accident to be reported, even if not accurately. It came four years after the American scientist Edward

Teller (1953) had opened up the discussion on reactor accidents in a speech to a group of nuclear experts. Windscale is, still today, probably the West's worst nuclear accident. Documents released in 1988 under the 30-year rule show convincingly that the British government for political reasons decided to censor the report on this accident.

Kyshtym is a big nuclear industry complex in the southern part of the Ural Mountains between the cities of Sverdlovsk and Tjeljabinsk. It is the first installation in the USSR to produce plutonium for nuclear weapons. It went into operation in 1948. The first information about an accident in this installation came through a 1976 article in *New Scientist* written by Zjorjes Medvedev, a Soviet refugee scientist. A substantial release of mostly strontium-90 took place some time in 1957–1958 (Medvedev, 1980). No details about what caused the accident are known. According to recently published satellite maps an area of 250 km^2 is isolated, and approximately 40 villages in the contaminated region are empty (*Ny Teknik*, 1988). The industrial complex in Kyshtym is still in operation. Approximately 10,000 people are working in the plant. Fuel from the Finnish reactors of Soviet design, which operate in the nuclear power plant in Loviisa, is returned to this plant (*Hufvudstadsbladet*, 1990).

On 28 March 1979 a major accident occurred at the Three Mile Island Unit 2 reactor. Pumps supplying water to the steam generators failed. When the flow of water stopped, the safety system shut down the steam turbine and steam generator. The pressure in the reactor increased, and a valve, above the pressurizer, opened as designed to relieve the pressure. The reactor automatically shut down within eight seconds. Emergency feedwater pumps were started to remove heat from the reactor core. Two closed valves prevented the water from reaching the system. The operators did not notice the problem, and the relief valve (which was opened intentionally) did not close as intended when the pressure in the reactor decreased. A "loss of coolant" accident was occurring and continued for more than two hours until a backup valve was closed. The loss of coolant accident was over when the valve was closed, but other methods were still needed to continue to cool the core.

Some reports state that TMI was the worst nuclear accident that has happened in the West. This position should, however, be reserved for Windscale because in the case of Three Mile Island the off-site consequences were minor compared with those of Windscale.

1.2 The Costs

Very little can be said about the cost of nuclear accidents. This is especially true in the case of the Chernobyl accident. Newspapers have published varying estimates of these costs. The direct cost in the Soviet Union is, according to one news item, four billion rubles; according to another, it is fourteen billion rubles. Ramberg (1986, p. 317) gives the figure of nearly three billion dollars. This includes the lost electrical generation and the expense of relocating 135,000 people. If to this is added the indirect costs, e.g., for lost production, then this amount can be doubled. These are of course so-called ball-park figures. They are based on loose estimates. As there are neither easily identifiable payers nor sufferers, these estimates remain an abstraction.

Cost estimates for Chernobyl have increased with time as more is known about the consequences and the cost of dealing with them. Without any kind of precision, experts today put the total cost at somewhere between fifty billion and one hundred billion dollars.

Hamman and Parrot (1987, p. 230) give a list of items which should be included in "the bill for Chernobyl." This list includes:

- The cost of resettlement of 135,000 people including new homes, transportation, and replacement of personal belongings.
- The value of the towns of Pripyat and Chernobyl, which will remain uninhabitable for some time.
- Lost agricultural production from contaminated lands.
- Expenses of medical treatment of Chernobyl victims.
- Expense of establishing screening and monitoring programs for the evacuees.
- The value of lost electrical production from the Chernobyl plant.
- Lost investment in construction on the planned Unit No. 5.
- The lost productive value of the human beings who were either killed by radiation or whose lives will be shortened by exposure to it.

Hamman and Parrot estimate twenty-five billion dollars as the cost of Chernobyl.

Only one general conclusion can be drawn from the estimates mentioned above – nobody knows the cost of Chernobyl. Is there an answer to the question? Is it at all possible, with the economics toolbox available today, to assess the cost to society of an event like Chernobyl? The nearest equivalent would be to try to calculate the cost of a small war and that has not to my knowledge ever been done with any real credibility.

No serious scientific efforts have been made to estimate the costs incurred by countries in Western Europe. It is obvious that only partial costs for specific activities and losses can be estimated. A recent news item on Swedish television (26 April 1989) gave a cost estimate of four hundred million Swedish crowns as the cost of the accident for Sweden. Estimates like this exist in all European countries, but they can easily vary by a factor of ten depending on what implicit assumptions have been made. Economic impacts fall into four main categories:

- Costs calculated as resources diverted from other purposes.
- The cost created by disturbances in agriculture and in food trade.
- Long-term costs for the energy industry created by disturbances in nuclear energy programs. These costs cause second-order impacts on the production system in the affected countries.
- Costs derived from health effects.

Health-care issues are perhaps the most difficult to analyze from an economics point of view. There cannot be any certain knowledge of what the purely medical health impact of Chernobyl will be. A Soviet scientist (Swedish TV, 26 April 1989) recently estimated the additional number of cancer cases as approximately 20,000 during the next 20 years. To assess the accuracy of this estimate, and then translate it into a monetary equivalent, is a rather difficult, perhaps impossible, task. Obviously cleaning the power plant in Chernobyl will create substantial costs in the health sector. More than 4,000 Estonian workers have been involved in the salvage operations. Of these four have died, eight are permanently disabled, and 224 are seriously ill (*Rahva Hääl*, Newspaper of the Estonian Communist party, 26 April 1989).

I conclude this discussion of costs with four simple assumptions. First, one core meltdown with serious environmental consequences will occur for every 15,000 reactor years; second, the cost of this accident is forty-five billion dollars; third, the net electrical power produced by a reactor is 600 MW; fourth, the cost of one KWh is five cents. If the industry has to cover completely the cost of these accidents, it would mean an increase of less than 1.5% in the price of the electric power produced by nuclear power plants. This calculation is of course to simple to be of any practical use except as a starting point for discussions on ways to tackle the problem of liability and insurance.

It has been repeatedly stated that Chernobyl cannot happen elsewhere – at least not in a Western industrialized country. A core meltdown is an exceedingly improbable event. The whole nuclear energy program is built on the belief that core meltdowns must not and never will happen.

It is true that the Chernobyl reactor is of a different design from those used in the West. The fact, however, remains that the same general type of accident could take place in any other country with nuclear reactors. Incidents are frequent. One of the more visible of these was the accident in a reactor near Biblis, West Germany, in December 1987. This accident was logged with the reporting system for nuclear incidents in OECD, with a request that the accident should be kept secret (Charles, 1988).

A few statistical estimates of the probability of future reactor accidents have been made. Chow and Oliver (1987) have shown that the probability of at least one partial core meltdown incident in ten years is equal to 0.75. Islam and Lindgren (1986) have calculated a probability of 0.86 for the same type of incident. This is, of course, only a small fraction of the truth about the probability of a core meltdown for specific reactor technologies and different countries. The main point is that there is a significant statistical probability that additional core meltdowns will occur. This does not necessarily imply that every incident has to lead to loss of lives and environmental contamination. What actually will happen during the next accident depends on technology, training, and luck.

This book does not deal with nuclear reactor safety. I will, therefore, not go into a discussion on different methodologies to assess probabilities and consequences. The only point to be made is that nuclear catastrophes are extremely improbable, but they are not impossible.

An accident with consequences on the scale of Chernobyl is not unthinkable. An article titled "Barsebäck Can Explode" was published on December 6, 1986, in Sweden's biggest newspaper, *Dagens Nyheter*. The author was Lars Nordström, former head of the Swedish nuclear power inspectorate.

I am not going to discuss all assumptions – probable or improbable – which have to be made to design a scenario like the Chernobyl accident in another location. But let us look only at one fundamental aspect – the area of contamination in the immediate surroundings of the plant. We will make the assumption that an area within a radius of 30 km from the site of the accident will be completely uninhabitable and an area within a 50 km radius will be too heavily contaminated for any lasting human activities to take place.

Assuming that the evacuation of the population goes smoothly, an accident of the same size as that in Chernobyl in the Swedish nuclear power plant at Barsebäck would mean that Copenhagen and Malmö would cease to be part of the national economies of Denmark and Sweden. As a consequence of this, a population of more than 1.5 million would have to be resettled. There is nothing special about Barsebäck. I use it only to illustrate what the situation might be if an accident happens in a densely populated border area.

At this point most readers would say that this cannot be allowed. We have to assume that an accident on this scale will not and cannot happen. The main conclusion of a *gedankenexperiment* like this is that traditional tools of risk analysis cannot easily be applied to catastrophes that have consequences beyond the imaginable and insurable. This could be one reason why there is no simple solution to the nuclear energy problem confronting many countries. One fundamental question can be asked: Does a country have the right to expose a neighbor to the risk of a catastrophe which would stop the functioning of that country? I do not have an answer to this question. Empirical evidence indicates that the answer is "yes" as long as the probability is low enough. One reason for this answer could be that the question was not asked. Many problems relating to the use and acceptability of nuclear energy – and other high-risk technologies – are concerned with moral and ethical issues. This makes discussions extremely difficult and in many cases impossible.

1.3 Factual Description [2]

The Chernobyl reactor installation is situated about 100 km north-northeast of Kiev in the Ukraine on the banks of the Pripyat River, which flows into the Dnieper. The region is relatively flat with gentle slopes down to the river or its tributaries. Unit 4 of the nuclear power plant went into operation in December 1983. The reactor was a heterogeneous thermal neutron channel-type (pressure tube) reactor, in which graphite was used as the moderator, while the coolant was light water and a steam-water mixture that circulated through vertical channels passing through the core. The reactor core is a cylinder with a diameter of 11.8 m and height of 7 m. The thermal power of the reactor was 3200 MW. The mass of uranium in the fuel assembly was 114.7 kg.

On the night of 25 April 1986, 176 operational staff members and workers were at the site. In addition, there were 268 workers working on the night shift of the third construction stage. The core of Unit 4 contained 1,659 fuel assemblies with an average burn-up of 10.3 MW/kg, one additional absorber, and one unloaded channel. A shutdown for maintenance was planned for 25 April. Before shutdown, tests were to be carried out on one of the turbogenerators. The purpose of the experiment was to test the possibility of utilizing the mechanical energy of the rotor to sustain the unit's power requirements during a power failure.

On 25 April, at exactly 1:00 hours, the staff began to reduce the reactor power. The electric power for the unit's needs was switched to one of the turbogenerators. At 14:00 hours, the reactor's emergency core cooling system was disconnected from the multiple-forced circulation circuit. Because of control room requirements the removal of the unit from operation was delayed. Thus, the unit continued to operate with the emergency cooling system switched off. At 23:10 hours, the power reduction was resumed. When the automatic control system was shut off the operator was unable to eliminate the resultant imbalance in the measuring part of the control system quickly enough. As a result, the power fell below 30 MWt. At 1:00 hours, on 26 April, the operator succeeded in stabilizing the reactor at 200 MWt. A further increase in power was prevented by the small excess reactivity available, which at that moment was substantially below regulations. At 1:03 and at 1:07 additional main circulation pumps were switched on in addition to the six pumps already operating.

Since the reactor power was low and all eight circulation pumps were operating, the total coolant flow rate through the reactor rose above the levels permitted by the operating rules. The increase in water flow through the reactor caused a reduction of steam formation, a fall in steam pressure, and changes in other reactor parameters. The operators failed to sustain the steam pressure and the water level in the drum separators. Both pressure and water level dropped below the emergency level. To avoid shutting down the reactor, the staff blocked the emergency protection signals relating to these parameters. The reactivity continued to drop slowly. At 1:22:30 the operator noticed that the available excess reactivity had reached a level that required immediate shutdown of the reactor. Nevertheless, the staff decided to begin the experiments.

At 1:23:04 the emergency regulating valves of turbogenerator No. 8 shut. The reactor continued to operate at about 200 MWt, but the reactor power began to rise slowly. At 1:23:40 orders were given to send all control and scram rods into the core. The rods fell, but after a few seconds a number of shocks were felt as the absorber rods halted without plunging fully to the lower stops.

According to observers outside Unit 4, at about 1:24 hours two explosions occurred; burning lumps of material and sparks shot into the air above the reactor, some of which fell onto the roof of the machine room and started a fire.

As a result of the explosion, burning graphite started fires in over 30 places. Fires formed in the machine hall over one of the turbogenerators, in the reactor hall, and in the adjoining, partially destroyed, buildings. These fires were extinguished over a period of about three hours with the exception of the main mass of the core and moderator. Actions were then taken to control the burning mass and limit fission product release.

The damaged reactor was covered with compounds of boron, dolomite, sand, clay, and lead, which were dropped from military helicopters. About 5,000 ton were dropped between 27 April and 10 May, mostly between 28 April and 2 May. By 6 May, the release of radioactivity had ceased to be a major factor, having decreased to a few hundred curies (Ci), and fell to a few tens of Ci per day by the end of May.

Three surveillance zones were established around the damaged reactor: a special zone, a 10-km zone, and a 30-km zone. In these zones, strict dosimetric monitoring of all transport was organized and decontamination points were established. At the zone boundaries arrangements were made for transferring personnel from one vehicle to another to reduce transmission of radioactive substances.

The accident involved the release of some 50 megacuries (mCi) of condensable radioactive fission and transuranium activation products. This is about 5% of the total fission product inventory of the reactor core. Approximately

Table 1.1. Released radioactivity from Chernobyl affecting the food chain.

Radionuclide	Radioactive half-life	Emitted radiation	Radioactivity released (Bq)
Sr-89	53 days	$\beta + \gamma$	8.0×10^{16}
Sr-90	28 years	β	8.0×10^{15}
Ru-103	40 days	$\beta + \gamma$	1.2×10^{17}
Ru-106	1 year	β	6.0×10^{16}
I-131	8 days	$\beta + \gamma$	2.6×10^{17}
Cs-134	2 years	γ	1.9×10^{17}
Cs-137	30 years	$\beta + \gamma$	3.8×10^{16}
Ce-141	32 days	$\beta + \gamma$	1.0×10^{17}
Ce-144	284 days	$\beta + \gamma$	1.0×10^{17}
Np-239	2.4 days	$\beta + \gamma$	4.2×10^{15}
Pu-238, etc.	13 years +	α	5.0×10^{15}

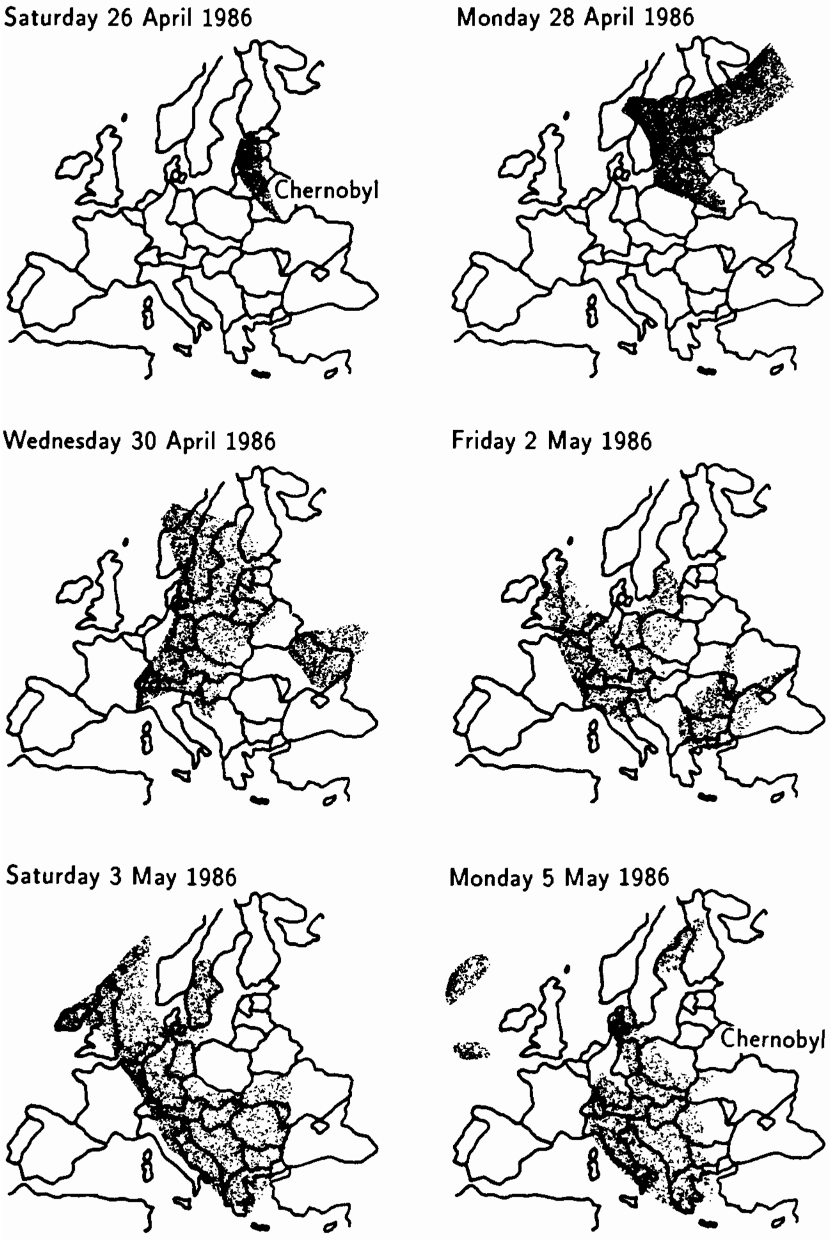
(Source: Carter, 1988, p. 3.)

half of this amount relates to radionuclides of significance to the food chain (see *Table 1.1*).

Radiosonde data close to the reactor indicate that the plume of released material reached a height of up to 3 km before horizontal transport began. About half the emission of condensable products fell in an area extending to about 60 km from the accident site, while the rest was deposited over an area of Europe of some 10 million km^2 and beyond (Zifferero, 1988, p. 4).

The movement of the contaminated air masses throughout the period of release is shown in *Figure 1.1.* From 26 to 28 April, a high-pressure area over northeast Europe carried the plume northward, at first affecting the USSR, then later northeast Poland and Scandinavia where radiation monitors in Sweden and Denmark indicated abnormally high readings. The triggering of these monitors was the first indication in Western Europe that a significant nuclear accident had occurred. Although some national systems and the European Communities (EC) reporting systems for environmental radioactivity contamination and food contamination went into the alert state, it was not anticipated that much worse was to follow because, until Chernobyl, accidental releases had been thought of as short duration events.

The most significant factor influencing the rate of contaminated fallout from the cloud was rainfall. This is well illustrated by the fact that the contaminated air masses, which had passed over Luxembourg and Belgium on 2 May, gave levels of fallout that were four or five times higher in hilly areas of the United Kingdom on 2–3 May where rainfall occurred particularly over high ground in North Wales, the Lake District, and Scotland although these areas were more than 2,000 kilometers from Chernobyl. A similar pattern was seen in Austria where the low-lying area around and to the north and east of



Saturday 26 April 1986

Monday 28 April 1986

Wednesday 30 April 1986

Friday 2 May 1986

Saturday 3 May 1986

Monday 5 May 1986

Figure 1.1. Movements of contaminated air masses over Europe.

Table 1.2. Approximate percentage of dose in the first year contributed by individual foods.

Food	Average adult	One-year-old infant
Milk	30–60	40–90
Dairy products	1–10	<1–15
Cereals	5–50	<1–15
Lamb	1–15	<1–5
Beef	1–20	<1–20
Green vegetables and fruit	5–30	1–30

Vienna received a much lower amount of fallout than Upper Austria, despite the fact that this area was closest to the source of the release.

Although a number of fission products were detected in the fallout, only iodine-131 (I-131, half-life 8.1 days), cesium -134 (Cs-134, half-life 2.1 years), and cesium-137 (Cs-137, half-life 29.7 years) made significant contributions to the radiation dose. *Figures 1.2* and *1.3* show the general pattern of deposition of I-131 and Cs-134+Cs-137 measured by various governments and based on a survey carried out for the Commission of the EC by the UK National Radiological Protection Board. Within this broad pattern, large local variations exist depending on rainfall and topology.

Radiation from the fallout reached the population by a number of methods. External irradiation from the cloud while it was passing made an insignificant contribution to the radiation dose received by individuals, and inhalation of radioactive materials probably contributed only around 5%. Some 15% was derived from deposited radioactivity on the ground, and, since this effect lasts until the deposited radioactivity decays, it is still making a minor contribution. Between 60% and 80% of the total dose came from foodstuffs. This source became the principal concern of most authorities, not only because it was important but because it was the only pathway over which they could exercise some control.

It had been a relatively cold spring, and the agricultural crops were not at a very advanced stage. In the north cows were not yet put out to graze, so their food, which was fodder from the previous season or compound feeding-stuffs, was not contaminated. In the more temperate parts of Europe the grass/milk route was the most important source of ingested radioactivity, particularly for infants. *Table 1.2* shows some estimated ranges for the European Community, the one-year-old infant being the one with the highest calculated consumption of milk and dairy products.

Since most processed dairy products take some time to reach the consumer, most of the I-131 transfer was through the ingestion of liquid milk and fresh dairy products; the delay in consumption of the processed products allows I-131 to decay. The cesium levels took some time to build up in milk since

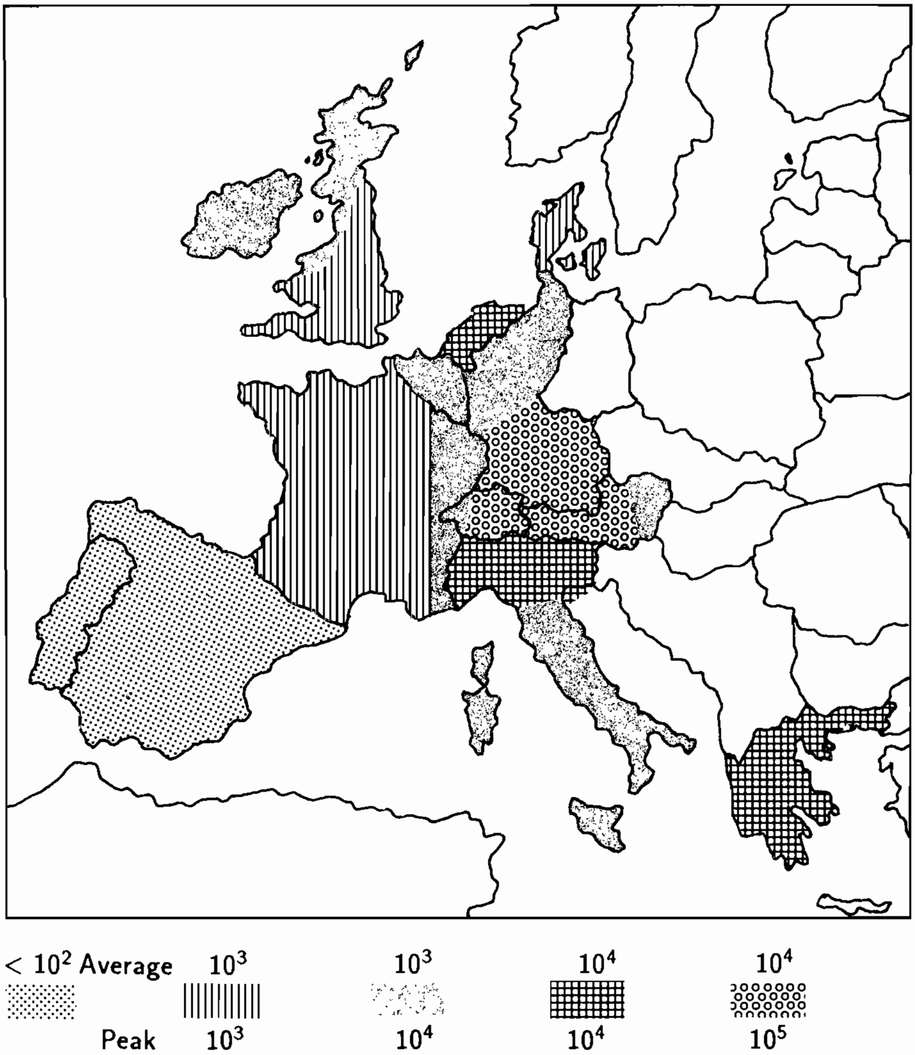


Figure 1.2. General pattern of deposition of iodine-131, Bq m^2. Values are rounded to the nearest order of magnitude.

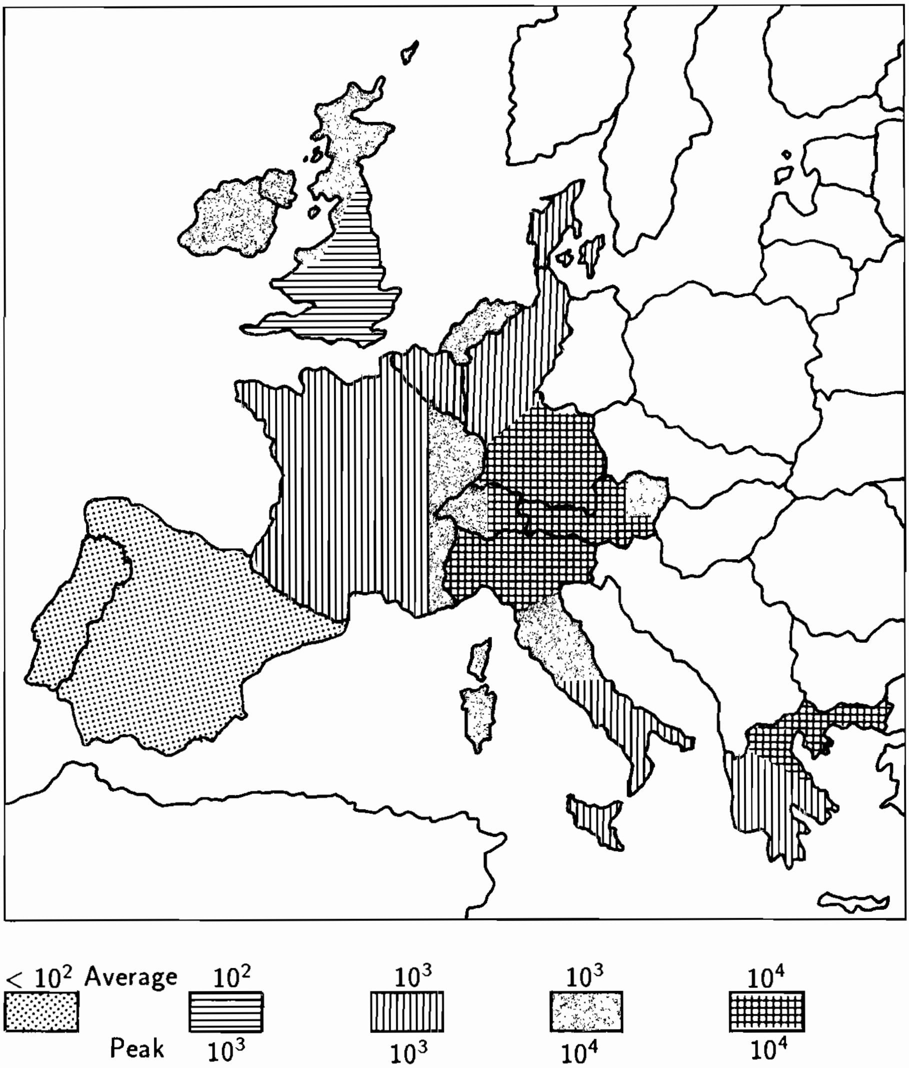


Figure 1.3. General pattern of deposition of cesium, Bq m^2. Values are rounded to the nearest order of magnitude.

it first had to reach a biological equilibrium in the body of the cow. As the season progressed, new herbage was growing, and, since in most lowland areas the recycling of cesium from the soil was very low, this new grass diluted the contaminated grass leading to a steady fall of cesium levels in milk and meat following a peak reached three to four weeks after the initial contamination. A second much lower peak was recorded during the winter months, when stored fodder, which had been harvested just after Chernobyl, was fed to farm animals.

Fruit and vegetables were affected by the fallout to a varying degree, depending on their state of maturity at the time of the accident. Since contamination was measured in activity per unit weight, becquerels/kilogram, the highest levels were found in leafy vegetables, which presented a relatively large catchment area for rainwater and had a high surface-to-weight ratio. Spinach, for example, reached as much as 10,000 Bq/kg of I-131 in Austria and several thousand in southern parts of the Federal Republic of Germany and northern Italy. Other green vegetables were contaminated but not to the same degree. Cs-137 levels of these products were at the outset 25%–35% of the I-131 levels. Both Cs-137 and I-131 levels fell rather rapidly partly due to decay of the I-131 but also because of new growth and some wash-off. By the end of the third week in May, I-131 had reached insignificant levels and Cs-137 was 10%–15% of peak levels on these crops. Special problems were encountered in upland regions, particularly in the UK, and contamination in sheep persisted into 1988 at levels where control on slaughtering still had to be exercised. Reindeer in the extreme north, some game, and wild mushrooms also showed high levels of radioactivity; special arrangements had to be made to process a relatively large amount of contaminated durum wheat, which after processing yielded foodstuffs within legal limits. Excessive contamination levels in foodstuffs imported into the EC from Eastern Europe were found mainly in live horses, nuts, tea, and herbs; all products difficult to control.

In summary, probably less than 1% of the food produced in the 1986 harvest in Western Europe exceeded limits where special measures were applied, and, apart from the problems mentioned above, by 1988 contamination levels in farm produce were beginning to approach pre-Chernobyl background.[3]

This book starts with a description of monitoring and assessment methodology and implementation in Europe. Franz Schönhofer was directly involved in these activities in Austria and gives an overview of how these fundamental activities were organized. Information on levels and types of contamination present is not enough for decision making. The health effect of radiation is the cornerstone of knowledge on which the immediate policy response after a nuclear accident is based. In Chapter 3 László Sztanyik gives an overview of what is known about health effects of radiation.

Exposure to radiation can, to a large extent, be controlled by regulating the food chain. The actions taken in different countries are described in Chapter 4 by Paul Gray, who from his position at the Commission of the European Communities (CEC) headquarters in Brussels worked with these problems during the years after Chernobyl. In Chapter 5 Joanne Linnerooth-Bayer gives an extensive description of how various international organizations functioned after the Chernobyl accident. This is an important part of the international policy response and creates the foundation for future strategies at the national and international level.

The accident at Chernobyl was, as Hohenemser and Renn (1988) put it, the largest uncontrolled experiment in risk perception and risk management ever conducted. As with all uncontrolled experiments, its value to scientific studies is limited. Whatever conclusions can be drawn and whatever assessments can be made are, however, of value to decision makers responsible for maintaining society's preparedness to cope with unknown emergencies. There is probably no scientifically consistent method to analyze all impacts of Chernobyl.

The effects of the accident cover all aspects of society, and there is simply no way to avoid compartmentalization in descriptions of various phenomena. For this reason, media coverage has to be analyzed using one methodology, intervention-level policies have to be described using another methodology, and the actions taken by international organizations have to be described within their own context. This becomes very obvious in efforts to analyze "soft" aspects of what took place in Europe after Chernobyl.

The ways the general public acts and reacts in an emergency are described by Bruna De Marchi and Nicoletta Tessarin in Chapter 6, while Harry Otway in Chapter 7 gives an overview of how the press in Western Europe covered the accident and treated the sources of information available to them. The conclusions from the events following Chernobyl are drawn in the final chapter by Marc Poumadère.

We have also included an Appendix giving an overview of terminology and units.

The only way to deliver an overview of what took place in Europe after Chernobyl is to expose the reader to these fragmented views of the total picture hoping that he or she will be able to put the pieces together. The sheer volume of material prevents anyone from comprehensively reporting on all aspects of the reactions to Chernobyl, covering all countries receiving fallout. It is, however, possible to get a fairly realistic overview of the situation by studying groups of countries and then assuming that they are a good sample of the whole of Europe. This approach has been taken in this book, and we feel quite confident that the clarity of the message is not suffering from this partial coverage.

Acknowledgment

An early version of the factual description of the event was written by Paul Gray.

Notes

[1] At the operating temperatures of the reactors at Windscale, the neutrons being slowed down in the graphite caused lattice deformations. Energy was thus stored in the graphite matrix, which could spontaneously relax leading to dangerous overheating. This so-called Wigner energy was therefore released by periodic controlled heating of the graphite.

[2] This description is mainly based on documentation compiled by the USSR State Committee on the Utilization of Atomic Energy for the International Atomic Energy Agency experts meeting 25–29 August 1986.

[3] The information on foodstuff contamination is based on a preliminary draft by Paul Gray. A full account is given in Chapter 4.

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Chapter 2

Monitoring and Assessment

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2.1 A Historical Review

The testing of nuclear bombs in the atmosphere in the late 1950s and the early 1960s has led to widespread contamination of air, soil, water, and the biosphere. Many countries have started surveillance programs to monitor contamination. It can be assumed that the high contamination that was found, for instance, in the Scandinavian countries prompted efforts to enact the 1962 treaty of the ban on nuclear tests in the atmosphere. Since then the concentration levels of radionuclides in the environment has declined considerably partly due to decay and partly due to their removal to sinks where they are strongly bound and cannot be recycled into the biosphere. The basic idea of surveillance networks has changed from monitoring fallout, more or less as a means to follow the decline of the artificial contamination in the environment, to monitoring discharges from nuclear power plants and to preparing for the possibility of widespread contamination following a severe reactor accident or even nuclear warfare.

As levels of environmental contamination declined, so too did the interest in monitoring. Introduction of high-resolution gamma spectrometry as a routine monitoring method made it possibile to analyze a wide range of artificial radionuclides quickly, but costs for equipment rose considerably. Often it was considered too expensive to modernize these networks especially considering the low probability of severe reactor accidents and nuclear warfare.

In order to react quickly and to implement effective countermeasures, authorities require a lot of information, including aspects of detecting contamination; evaluating its geographical distribution, decay, and transfer to the food chain; and monitoring radiation dose impact on the population. This information is only available with well-trained personnel using well-organized monitoring networks.

2.2 Design of Monitoring Systems

The design of monitoring systems requires many parameters. In many cases monitoring systems have not been "designed," but have grown gradually from scientific interest in air contamination from university departments such as meteorology and aerosol physics. Researchers in health physics became involved as well. Monitoring systems have been developed that serve the needs which may be encountered in different countries. As will be discussed later, the mere existence and operation of monitoring equipment are not enough; communication systems must also be established. Political interests, public opinion, analysis of potential hazards, and financial resources to provide both technology and personnel play a very important role. The competence, for instance, of military and civil authorities might be important. Even the location of a country will influence the requirements of a monitoring system.

In spite of the different presuppositions some common requirements can be observed in existing monitoring systems in European countries. Radiation protection and measuring equipment in East Europe can be regarded as good as the equipment in West Europe.

2.2.1 Scenarios

Many possible scenarios of radioactive contamination must be considered. In principle widespread contamination may occur by explosion of nuclear warheads, by a severe accident in a nuclear installation, or by reentry of satellites bearing nuclear reactors or isotope batteries into the atmosphere.

Contamination resulting from an explosion of a nuclear warhead will be extremely dependent on the type of weapon, the distance from the explosion center, and local weather conditions; however, it will be completely different from contamination resulting from other reasons regarding isotopic composition of fallout and potential health hazards.

In the case of a severe accident in a nuclear installation the impact will depend first of all on whether it occurs in a reprocessing plant or a power station. Only long-lived radionuclides can be emitted from a reprocessing plant. A reactor can discharge short-lived and long-lived radionuclides, and contamination will depend heavily on the type of accident and the type of reactor. This is easily demonstrated by three severe accidents that have already happened: the accident at Windscale was followed by medium-range contamination (Dunster, 1987); the accident at Three Mile Island had only local effects that were due to gaseous radionuclides (Gerusky, 1987); the Chernobyl accident spread contamination via aerosols over almost all of Europe (a short survey is given in Schönhofer *et al.*, 1986) and traces of contamination could be detected even in North America (Juzdan *et al.*, 1988; Broadway *et al.*, 1988; Ministry of National Health and Welfare, 1986), Japan (Radiation Safety Study Mission, 1986), and Taiwan (Chien and Chen-Jong, 1988).

Satellite accidents are different from nuclear ones. Either the satellite burns completely on reentry into the atmosphere – contamination is then widespread at high altitude and comes down slowly in the course of years – or the reactor is broken into pieces, which then fall to earth. In the case of the satellite that crashed in Canada in 1984, the sizes of radioactive fragments were found to be from submillimeters to large assemblies of construction material like pipes and beryllium rods (Meyerhof, p.c.). Because volatile radionuclides like iodine or cesium will evaporate at high altitude, they are not considered important in satellite accidents.

2.2.2 High elevation: "Early warning"

In the case of heavy contamination early warning is essential. Gamma radiation, which in nearly all cases will be associated with radioactive material emitted in an accident, can be easily measured. Many instrument systems can measure dose rates caused by gamma radiation from environmental levels (and therefore well below any critical dose rate) up to extreme high levels. The higher the level the faster and easier it can be measured. Therefore, from the side of instrumentation all requirements for fast early warning can be met.

Another question is the density of measuring station networks, which obviously depends not solely on geographical parameters of a given country but also on political and financial considerations. This is easily demonstrated by the fact that Austria regarded 336 stations on 83,855 km^2 as necessary (Schönhofer *et al.*, 1986), while in Sweden 25 were in operation on an area of 449,964 km^2 at the time of the Chernobyl accident.

The combination of dose-rate measurements with meteorological parameters, linkages of these data via computers to produce isolines of contamination, and forecasts of the contamination situation are regarded by most experts not only as easily achievable by appropriate systems, but also as absolutely necessary. Experience and know-how are available from systems for remote surveillance of nuclear power stations (Eder and Starke, 1987). Data transmissions from remote sensors and linking of different parameters to give a forecast are well-known techniques for on-line monitoring of, e.g., chemical plants (Slater, 1987). Besides early warning this equipment can be used to follow decay of dose rates after an accident and to achieve estimations of the doses received by the population from external radiation.

2.2.3 Lower levels

In most countries monitoring systems exist that are capable of detecting low, and even extremely low, concentrations of artificial radionuclides. Regulations limit emissions from nuclear installations that have to be controlled. Possible emissions from a nuclear power station that is close to a border must be controlled as well. Applications of radionuclides in nuclear medicine and technology are other sources of environmental contamination.

Environmental gamma-ray dose rates may vary considerably depending mostly on geologic parameters like uranium content in soil or rock as well as on the contribution of cosmic rays, which varies with sea level (Tschirf *et al.*, 1975). Even aerosol activity measured by gross-beta-counting may vary as much as a factor of 10 depending on meterological parameters (Kronraff, p.c.). Dose rates and gross-activity-counting are therefore not capable of detecting small elevations reliably. Moreover, even in the case of high elevations information based solely on a rise in environmental radioactivity irrespective of its nature is not sufficient. To determine the amount of different radionuclides much more sophisticated instruments must be used, which need skilled and well-trained personnel. Measurement and sampling infrastructures must be provided even in "normal times"; they cannot be established *ad hoc* in an emergency situation. So countries having regular programs for monitoring radioactivity were prepared for the Chernobyl accident at least with regard to instrumentation, and there was no lack of measuring equipment.

2.2.4 Instrumentation

The results from measurement methods and instruments can be roughly classified into two categories: one group gives unspecific information ("there is some radiation"); the other provides the type and amount of radionuclides present.

One of the unspecific methods still employed is the above-mentioned measurement of gamma-ray dose rates for the purpose of early warning and determination of external radiation dose rates. Measurement of gross-beta-activity of aerosols is still used in some countries for early warning, but it has been replaced in most cases by nuclide-specific analysis.

Measurement methods and equipment have gone toward highly specific determination of radionuclides. Measurement of some unspecific radiation quantities is not enough. To calculate the dose received by the population, the concentration of single radionuclides has to be determined anyway, therefore gross-activity measurements have been replaced in most countries generally by nuclide-specific ones. Development of germanium detectors and modern multi-channel analyzers has made fast measurements by high-resolution gamma spectrometry possible because sample preparation is virtually unnecessary and data evaluation can be done automatically using personal computers. Nevertheless, determining most beta- and alpha-emitting radionuclides is still a laborious task because they must be purified chemically before measurement is possible. In the course of the last 30 years little has changed in this respect, except with the introduction of new generations of liquid scintillation counters that allow better control of results and compute rough, but very fast, estimates of beta-activity in certain important media like milk and water (Schönhofer and Weisz, 1987). This time discrepancy, which is necessary to obtain results, has led in many cases to a somewhat distorted view of planning for emergencies, overemphasizing the importance of gamma-measurements and neglecting the need for determining such important radiotoxic nuclides like Sr-89, Sr-90, or Pu-239.

2.2.5 Media to be measured

No general "recipe" can be given of which media should be measured. Range of distribution and amount of the different radionuclides emitted will depend mostly on the type of accident and on meteorological conditions. If and to what extend foodstuff will be contaminated depends also on the time of the year.

Special cases like accidents at reprocessing plants or the crash of a satellite will not be considered here, but interest will be focused on events that result in widespread contamination as in the case of a severe reactor accident, especially of the Chernobyl type, or explosion of a nuclear warhead.

In principle the possibility of warning exists, and models have been developed to calculate the distribution of aerosol activity and deposition (ApSimon *et al.*, 1985; van Egmond and Kesseboom, 1983; Gudiksen, 1986). The calculations that were performed after the Chernobyl accident differed considerably in many respects from the actual contamination pattern. However, shortly after the accident many source terms could not be identified precisely and even after more information became available meteorological forecasts were contradictory. In the case of a nuclear war no warning can be expected and international meteorological networks are likely to break down. So each country must rely on its own measurements.

Provided efficient monitoring systems exist, contamination will be identified first in aerosols and deposition either directly or via the elevation of gamma dose rates. Activity of aerosols must be measured to calculate the inhalation dose. Determination of gaseous I-131 should complete the aerosol measurements. Radioactive noble gases like Xe-133 and Kr-85 are difficult to measure because they need special isolation and enrichment techniques; moreover Kr-85 is a beta-emitter. The few measurements that have been performed, for instance, in the Federal Republic of Germany (Weiss *et al.*, 1986) after the Chernobyl accident have shown that the contribution of these gases to the overall dose was negligible.

Activity of deposition is important in several respects. First of all deposition on the ground is responsible for the external dose received by the population; this can be calculated from gamma-radiation dose rates. However, nearly all contamination of food results from deposition. If vegetables or cereals are in the fields or fruits are on the trees, then they will be contaminated directly. Quick transfer from leaves to growing fruits occurs. Grass, which is contaminated by direct fallout, will via the food chain cause contamination of milk, milk products, and meat. Therefore, the contamination situation of food will depend strongly on the time of the year. Radionuclides deposited on soil will cause some contamination of food via root uptake, but this will, with the exception of the forest ecosystem, have much less of an effect than direct contamination.

In karst regions precipitation may be transferred very fast to drinking water, therefore monitoring of drinking water in these regions should be undertaken. Samples taken after the Chernobyl accident showed that drinking water processed from surface water reservoirs was only slightly affected. The reason for this is twofold: first, the contaminated precipitation is diluted within days to unmeasurable concentrations even in the surface layer; second, most radionuclides are removed in the course of processing the water (Heintschel, 1986). Since in precipitation the radionuclides are present in a concentrated form, cistern water will be the highest contaminated consumption medium. Consequent monitoring of single cisterns, which generally serve a small number of people, is not expected to be possible, so a general recommendation not to use cistern water may be the only solution to this problem.

A serious problem may be the transfer of radionuclides from surface water to fish via the food chain. The accumulation is slow, but depending on the type of lake the contamination of certain fish species can reach extreme levels and may persist for many years. The accumulation processes are not yet fully understood and are a matter of extensive research (Håkanson *et al.*, 1988).

It should be mentioned that computer codes have been developed [for instance, ECOSYS (Paretzke and Jacob, 1987)] that attempt to estimate food contamination depending on the time of year. Aerosol activity and dry and wet deposition are needed as input parameters. Owing to the fact that transfer factors may vary by several orders of magnitude under different conditions, only very rough predictions can be expected.

It is evident that in the very first stage of widespread contamination environmental samples are to be measured predominantly. It has to be kept in mind, however, that for several important radionuclides (like Sr-89, Sr-90, and Pu-239) results can only be achieved after time-consuming chemical separations have been performed. Especially in the case of fresh fallout, several radionuclides may disturb precise analysis of Sr-89 and Sr-90 (Hellmuth, 1987).

Since I-131 and I-132 (from Te-132) are transferred very quickly from pasture to milk (approximately after two days a maximum is reached) control of milk has to start very soon after contamination occurs. Owing to the short half-life of I-131 (8.1 days), the contribution of I-131 to the dose can be neglected after about one month. Rigorous control of milk in the first few weeks of contamination can provide an effective, yet not-too-expensive, countermeasure to reduce doses delivered to the population and especially to the risk group of children (Schönhofer *et al.*, 1986). In most countries milk for direct consumption amounts only to a small part of all milk produced. Less contaminated milk can be used for drinking while higher contaminated milk for making cheese where not only I-131 will decay during ripening but also Cs-134 and Cs-137 will be depleted (Lagoni *et al.*, 1963). Radiocesium and radiostrontium show a maximum in milk after about two weeks; therefore measurement of these radionuclides is not so urgent.

Transfer of I-131 and radiocesium from fodder to meat is much slower. Therefore monitoring of meat need not start right away. I-131 has a short half-life and therefore is of little importance. Sr-90 is transferred to meat only to a negligible extent.

If direct contamination of grass occurs then surveillance of grass and hay will be necessary to have a forecast on possible contamination of milk and meat also for wintertime and to start countermeasures in cases where it seems to be necessary. Care should be taken in calculating contamination because the direct Chernobyl fallout showed transfer lower by a factor of three to four compared with experiments with soluble cesium salts or grass contaminated by root uptake.

Sampling of precipitation and aerosols will normally be carried out by stationary equipment installed at positions that depend on geographical criteria. For gamma-radiation dose-rate meters the same criteria will apply, but portable equipment both for aerosol sampling and for dose-rate measurements exists and might be valuable for completion. Very big NaI(Tl) detectors have been successfully employed for surveillance from air (Andersson and Nyholm, 1986).

Since in "normal times" contamination of environmental media and food are mostly below any detectable concentration, no separate sampling organization is justified, but existing ones must take over this function. European countries assign authorities to control and monitor the quality of drinking water, agricultural products, and so on. Procedures to coordinate sampling and transportation of environmental media should be developed before an accident occurs. Also training or at least written guidelines regarding sampling techniques should be provided to acquire representative and comparable samples.

The above-mentioned media must be measured from the standpoint of radiation protection. No doubt there are many reasons to measure certain media, i.e., political, economical, and psychological reasons, for export and import foodstuff has to be checked. From experience it can be said that if public opinion is interested in the contamination of parsley or black currants or strawberries or sand in playgrounds, then it will have to be measured. If exporters or importers need a certificate stating that an item, such as Russian vodka, caviar, salicylic acid, plastics granulate, food produced long before the Chernobyl accident, beef from Argentine, lamb from New Zealand, is free of radiocesium, then it must be measured even though it may have been impossible for that item to be contaminated.

2.2.6 Long-term concern

Certain foods and media must be measured and studied over a long period. In forest ecosystems Cs-137 can circulate very effectively (Schell *et al.*, 1988), and contamination of wild berries, mushrooms, and venison will even rise in the years following a severe contamination (Bengtsson, 1986; Schönhofer and Tataruch, 1988). Reindeer in parts of northern Scandinavia (Bengtsson, 1986) and sheep in Cumbria, England (Howard, 1987), are other examples of animals that have experienced long-term contamination. In addition long-term contamination has also been measured in fish (Håkanson *et al.*, 1988; Schönhofer *et al.*, 1986).

2.3 Assessment

Achieving an overview in the situation of widespread contamination is a complicated task. Much experience has been gained by studying bomb fallout, but the fallout deposition from bombs occurs slowly and rather evenly. The Chernobyl accident was therefore surprising because of both the quick and the extremely nonuniform distribution. So reaction within a short time was necessary, but a very large number of measurement data were needed to judge the situation. Monitoring networks with enough equipment and personnel for measuring are a presupposition, but the data acquired have to be collected, checked for their plausibility, and combined to form a rough overview. On this basis feedback has to influence monitoring in order to refine knowledge of the situation. Then decisions on countermeasures can be made. The effect of countermeasures must be checked. In addition countermeasures often create new problems. For instance, forbidding the feeding of contaminated whey to pigs is an efficient way to lower the radiocesium concentration in pork, but this creates the problem of how to dispose of the whey; prohibiting the spread of contaminated sewage sludge on fields might prevent additional contamination of soil, but for the most part no storage facilities exist for this sludge.

It is therefore to be assumed that it would be favorable to establish before an accident a group comprising governmental authorities responsible for the health, environment, internal affairs, military, trade, economics, finances, and agriculture of the country and experts from various sciences like radiation protection and meteorology. During an emergency this group should meet regularly to make decisions. Another important step would be to establish a small group of experts to collect all available data and combine them to form a situation report. This group should keep in contact with the mass media to distribute the latest news on the contamination situation. Both groups should be as flexible as possible because no contamination situation can be predicted, no generally accepted response to it can be evaluated or learned.

2.4 Communications

In the previous sections many technical aspects of monitoring and assessing radioactive contamination have been discussed. Also some aspects of organization have been mentioned. Communication paths may be considered equally important, as was demonstrated in the case of the Chernobyl accident.

According to my knowledge there was almost no official communication at the international level – at least not in the first few days. No warnings or information was given during the first days by the Soviet authorities to any other country or international organization. (It still is an open question whether this would have helped much in handling the impact, because exact prediction of contamination is obviously not possible.) Most information seems to have been spread by mass media (which were seldom reliable) and especially by private communications between scientists involved in measurements and assessment, who passed the information to their authorities.

Communication at the national level seems to have been a problem as well. The administrative machinery in most countries is based on strict hierarchy through which it is not possible to transfer information quickly. Too many authorities were involved with their own hierarchies. In the course of the first days, channels had to be established to pass information quickly to competent persons. The human factor was also evident: some scientists seeking publicity presented only the highest values, which exaggerated the situation;

scientists even carried results in a briefcase to ensure that they could present the measurements first to the authorities.

The combination of incomplete information, single measurement results, and telephones continuously blocked by scared people seeking personal information caused in some countries a communication chaos. As a result regular work and the transfer of information were hindered severely in the first days. It was very difficult to interpret the flood of single results because they were so widespread both geographically and with regard to the media. It took at least a week until slowly, a clear picture of the contamination situation in Europe developed from different information.

It is concluded that for handling the impact of large accidents better communication pathways must be installed, irrespective of their costs.

2.5 Monitoring Networks and Assessment in Five European Countries

Almost all European countries have more or less elaborate monitoring networks. Long after the Chernobyl accident several countries installed or extended automatic networks obviously owing to political and public pressures. It is to be hoped that monitoring on a discontinuous and nuclide-specific basis, which is necessary for assessing the contamination of the environment, food, and the public, will not be neglected in favor of costly automatic networks (which in the case of a severe accident may provide a quick warning, but no information on isotopic composition, chemical form, and contamination of the food chain).

The monitoring networks of some European countries as they were in existence in 1986 are described below, and the results of their assessment of the Chernobyl accident are also reported. Only qualitative results are given, because it is the aim of this chapter to give a quick overview. Finland and Sweden were chosen as examples of how the contamination was first detected in Scandinavia. Other countries were chosen because they could provide good documentation of the contamination situation. They reflect different contamination levels as well as different geographic and seasonal situations. Only official reports are presented in the descriptions. The vast amount of reports and scientific papers on limited aspects of the contamination path or local problems could of course not be considered here. All official reports are well in accordance with the actual contamination situation and therefore reliable. Data sources are provided for further information.

2.5.1 Finland

The description is based on studies done by the Finnish Centre for Radiation and Nuclear Safety (STUK, 1986a and 1986b).

Monitoring Networks

In Finland a radiation-monitoring network consisting of approximately 270 measurement stations is run by the Ministry of the Interior and the Finnish Defense Forces. They are equipped with simple Geiger counters and measure every second day. An aerosol measurement network consisting of 10 stations is run by the Finnish Meteorological Institute. It is not nuclide specific but acts as a warning system.

For environmental samples and foodstuff the Finnish Centre for Radiation and Nuclear Safety (STUK) also routinely runs a monitoring program. Aerosols are collected with high-volume samplers in Konala (Helsinki) and north of Helsinki as well as in the vicinity of the nuclear power plants of Loviisa and Olkiluoto. Precipitation is collected with high-surface samplers normally at four stations in the south and west of the country, but there are small samplers at an additional 24 stations. Samples from five major rivers are analyzed four times a year; the tritium content of some lakes is also measured. From the surrounding sea nine samples are taken usually once a year. In addition, bottom sediments and fish samples along the coast are collected. Concerning foodstuff, emphasis is on measuring the radioactivity of milk: milk and dry milk is controlled from several parts of the country and more intensively near Loviisa and Olkiluoto. Samples of wheat and rye as well as beef and pork are gathered from the main production areas; vegetables and fruits are sampled as well.

Whole body counting is performed on control groups from Helsinki, Loviisa, and Olkiluoto yearly. Lapps who are a risk group for radiocesium incorporation are monitored in cooperation with the University of Helsinki.

Assessment

During the evening of 27 April 1986 at the measuring station of Kajaani (approximately in the middle of Finland) dose rates between 70 and 100 μR/h were measured after a heavy rain shower. These rates were interpreted as a "radon peak," which had occurred several times in previous years. (The aerosol system was not operating owing to a state employees' strike.) On Monday, 28 April, news came from Sweden that at Forsmark fission products had been detected and that radiation levels were rising. This caused intensification of measurements. On Tuesday, 29 April, radiation levels rose considerably, especially in the western part of the country. On 30 April the highest level of 400 μR/h was measured in Uusikaupunki and afterward the levels decreased.

On the morning of 30 April the state employees concerned with monitoring and meteorology returned to work. Calculations on the origin of contamination and extensive monitoring could start. From the dose-rate network and from air monitoring a rather quick, semi-quantitative overview was established on the approximate geographic distribution of contamination.

The frequency of sampling air and precipitation was increased, and the number of samples especially of foodstuff was also increased. A network of 53 local laboratories based at communal food and milk inspection laboratories started measurement of milk, drinking water, and vegetables with simple equipment, thus freeing the STUK from routine work for more elaborate and complicated measuring programs.

Since the growing season for grass and most vegetables had not yet started direct contamination did not occur and the concentration of I-131 and Cs-137 was very low in milk: typical values in high fallout areas were approximately 30 Bq/l for I-131, less than 3 Bq/l for Cs-137, and less than 0.05 Bq/l for Sr-90. (This is in sharp contrast to Central Europe, where direct contamination was the reason of very high levels in foodstuff.) Since the measured values were well below the action limits of the Finnish authorities no restrictions were posed on the sale of foodstuff, but instead general recommendations were issued to minimize the radiation effects.

Most of the measurement programs resumed their usual activities after some time. As it could be foreseen from experience with nuclear bomb fallout, the levels in certain mushrooms, wild berries, and especially in certain fish (e.g., perch and pike) rose considerably in 1987 and 1988 (Rantavaara, 1987; Saxén and Rantavaara, 1987), so more intensive monitoring was necessary of these items. Even in the case of this higher contaminated foodstuffs authorities regarded recommendations to limit consumption as sufficient countermeasures. Since northern Finland (Finnish Lapland) received little contamination no problems arose with contamination of reindeer.

2.5.2 Sweden

The description is based on reports from the Swedish National Institute of Radiation Protection (SSI, 1986a and 1986b) and the Statens Haverikommission (1986).

Monitoring Networks

Since the end of the 1950s, 25 stations equipped with ionization chambers 2.5 meters above ground have been in operation by the Swedish National

Institute of Radiation Protection (SSI). They register continuously the gamma radiation from both ground and cosmic rays. Only three stations transmit data automatically via telephone to a computer at SSI.

The Swedish National Defense Research Institute (FOA), which from 1978 until 1983 was connected to the SSI, runs a system of high-volume aerosol samplers that normally detects very small amounts of radionuclides by high-resolution gamma spectrometry. The FOA also has access to army airplanes and helicopters to take air samples at different heights, to record measurements from the air, and to transport equipment and personnel to remote areas quickly to perform *in situ* measurements with portable germanium detectors.

At the SSI routine measurements of milk were run before the Chernobyl accident. Routine programs concerning environmental surveillance of nuclear power plants currently exist.

Assessment

On 28 April 1986 at the nuclear power plant at Forsmark north of Stockholm increasing levels of contamination were detected. First it was assumed that they originated from the power plant. Reports from Studsvik (south of Stockholm) about enhanced radiation levels created some doubts. Aerosol analyses showed artificial radionuclides with ratios typical for a release from a reactor. Trajectories calculated by the Swedish Meteorological and Hydrological Institute showed that the air masses came from the direction of Latvia, Byelorussia, and the Ukraine. Sampling of aerosols was performed in short periods, samples in higher altitude were collected by airplane, and in-cloud measurements from a helicopter were done with a portable germanium spectrometer.

Very soon the SSI emergency organization was enlarged with experts from other fields, and external organizations contributed with measurements from research institutes, the nuclear power stations, universities, and the Swedish Geological Co. (SGAB).

SGAB started very soon to scan the country from the air, thus providing maps of geographic distribution of dose rates and deposition of Cs-137. It became evident that there was an extremely nonuniform contamination situation in the country: the most northern parts were not affected at all and the south had very little evidence of contamination. Locations in the north of Sundsvall, a belt toward Norway, and the surroundings of Gävle north of Stockholm were highly contaminated with local levels up to 200 kBq Cs-137/m^2.

A program was set up to monitor milk, and owing to grazing restrictions the I-131 concentration in milk was, except in single cases, well below 100 Bq/l. Also the Cs-137 concentration was typically around 50 Bq/l even in highly contaminated areas. (As in the case of Finland, the growing season had not yet started in the highly contaminated areas.)

A limit of 300 Bq Cs-137/kg was applied to all foodstuff. In general there arose no difficulties from this low value, because with few exceptions all foodstuff was well below this limit. Nevertheless, some foodstuff was extremely contaminated: certain freshwater fish in contaminated areas, moose (which is a major part of the diet for some groups of the population), and especially reindeer. Only 20% of all reindeer slaughtered in 1986 after Chernobyl had a Cs-137 concentration below 300 Bq/kg. It can be easily imagined that the accident made a big impact on the life of the Lapps who live mainly on reindeer breeding.

2.5.3 Hungary

The description is based on reports from the Hungarian Atomic Energy Commission (1986).

Monitoring Networks

As in many other countries the intensive testing of nuclear bombs in the atmosphere during the late 1950s and early 1960s was the reason for installing environmental monitoring networks. Radioactivity of aerosols is measured by the National Meteorological Service, surface and drinking water by the National Water Authority, and foodstuff and soil by stations of the Ministry of Agriculture and Food and the Ministry of Domestic Trade. Environmental radiation is also measured by the public health network of the Ministry of Health. The network was improved with regard to the surveillance of the nuclear power station at Paks. Also research centers and universities are equipped with the necessary instruments for environmental surveillance. All monitoring is coordinated by the Hungarian Civil Defense Organization.

Assessment

First traces of radioactive isotopes were detected in aerosol samples taken in the morning of 29 April. Ten continuously operating aerosol samplers (based on gross-beta-measurements) were read once or twice a day. From 30 April until 2 May northern and western Hungary showed the highest aerosol activities (from 15 to 84 Bq/m^3). A second peak was observed from 3 to 4 May in the western and southern parts (max. 44 Bq/m^3) and a third one from 7 to 10 May in the east and south (max. 30 Bq/m^3). After 30 May the concentration fell below 1 Bq/m^3. Nuclide-specific gamma spectrometric measurements were reported from Budapest and Paks. There also the ratios of aerosol-bound and vapor iodine were determined: the ratios varied, but the vapor iodine was in both cases higher than the aerosol-bound. The highest concentration for both was measured in Budapest on 2 May, namely, 14 Bq/m^3. The ground contamination was monitored in a nationwide survey from 1 to 19 May. As in all other countries it was found that the deposition pattern was nonuniform, but overall rather low compared with the Scandinavian countries or Austria. The highest contamination was measured in Budapest and in the western part of the country. The contamination values at the border to Austria reported by the Hungarian authorities correspond very well with the Austrian (for Austria low) contamination measurement. Since about 25% of Hungarian drinking water is taken from the Danube, this river was monitored also, showing a gross-beta-activity concentration of approximately 30 Bq/l at the entrance into Hungary.

Foodstuff was monitored as well. The highest average activity concentration of I-131 in milk in the higher contaminated areas was measured on 2 May with approximately 1.2 kBq/l. To reduce contamination of milk, grazing of cows was prohibited. People were advised to consume only milk from large dairies (where surveillance was easy to achieve), and to wash large-leafed vegetables carefully before consumption. Surface water was not used as a drinking water supply for Budapest. These were actually the only countermeasures introduced.

2.5.4 Switzerland

The description is based on material from Bundesamt für Gesundheitswesen (1986) and Bundesamt für Energiewirtschaft (1986).

Monitoring Networks

Three warning systems exist. One consists of six early warning stations (FWP) positioned near the border, which measure continuously the aerosol activity. If a preset level is exceeded an alarm is automatically sounded locally. Seven more stations without automatic alarms are distributed over the country. The second system is NADAM (network for automatic dose alarm and measurement). Twelve NADAM stations were operating at the time of the Chernobyl accident; the operation of all 55 stations was scheduled for the end of 1986. Also in this case an automatic alarm is given if a preset dose rate is exceeded. In the case of high contamination, 111 atomic warning stations (AWP) operated mainly by the police can be activated, but the dose-rate meters used by AWP can only measure dose rates higher than 1 mR/h.

Besides these stationary alarms three cars at different organizations contain the necessary measurement equipment. Additional cars can be equipped to do surveillance. For measurement of foodstuff, drinking water, or fodder specialized laboratories exist, which also in "normal times" record measurements and regularly take samples in the region to measure and to communicate the results to the National Alarm Center (NAZ). The army provides, in the case of an alarm situation, personnel, an army laboratory, and a surveillance helicopter.

Assessment

After first reports of contamination in Scandinavia on 28 April, the meteorological forecasts did not expect contamination of Switzerland for several days. The early warning stations were alarmed. In spite of the weather forecasts from the early morning of 30 April onward rising contamination levels were found at the warning stations. Monitoring networks were organized and after the first results were intensified to get a quick survey on the geographic distribution, which was possible though only 12 dose-rate meters were in operation in the western part of the country by using mobile equipment and helicopter scanning. (An excellent description of the organization is given in Bundesamt für Gesundheitswesen, 1986.) Owing to different meteorological conditions, the distribution was very uneven; those areas where showers had occurred were more contaminated. Radioactivity of aerosols showed a maximum on 1 May, a second rise was found between 3 and 7 May. On the whole the aerosol activities were approximately the same over Switzerland, but deposition was different depending on precipitation. It ranged from 8 to 85 nCi Cs-137/m^2 (296 to 3,145 Bq/m^2) with a maximum measured in Locarno (Tessin) of 270 nCi/m^2 (10,000 Bq/m^2). The published data on contamination of the surroundings of Lake Constance correspond very well to the data from the adjacent areas of southern Germany and Austria.

As in most other European countries emphasis was given to examining contamination of foodstuff, and soon it was found that internal doses from incorporation were higher than doses from external radiation. Milk, one of the most important foodstuffs, was monitored extensively. The region of Tessin recorded the highest deposition. The highest values in milk were also found here (up to 50 nCi I-131/l and 20 nCi Cs-137/l). Contamination in milk from dairies was markedly lower due to blending. As experienced in other countries milk from sheep had extremely high values for I-131. Also in vegetables the uneven contamination of the country was reflected.

On the basis of early measurements it could be calculated that the Swiss limit of 5 mSv (500 mrem), below which no countermeasures are regarded necessary, would not be reached. The possible dose reductions achievable by strict countermeasures were regarded as too small to justify their costs. The only official countermeasures taken were to use milk from southern Tessin for making cheese, to transport low-contaminated milk from northern Tessin to the south for consumption, and to ban fishing in Lake Lugano. Otherwise only time-limited recommendations were given regarding consumption of higher-contaminated foodstuff. Children and pregnant women were advised not to consume fresh milk and fresh vegetables in order to reduce iodine doses.

2.5.5 Austria

The description is based mainly on a study by Schönhofer *et al.* (1986).

Monitoring Networks

In 1957 the first station for aerosol surveillance was installed. In 1986 eight stations were operating. At these sites precipitation is collected on a monthly basis. In 1986 the rivers Danube, Thaya, and March in northern Austria were monitored mostly on the basis of monthly grab samples. Originally gross-activity measurements were used in environmental monitoring, but since 1979 high-volume samplers and nuclide-specific high-resolution gamma spectrometry were introduced as the routine method. In 1986 only a small program on food surveillance was in operation, and it was undergoing reorganization. Because no nuclear power station is operating in Austria, this surveillance system was mainly to monitor the environmental levels of radiation and to detect discharges from foreign nuclear power stations and from nuclear medicine. As well it had the task of preparing for nuclear accidents.

In 1975 construction of another system, the Early Warning System, was started. It consists of 336 stations across Austria, which measure the gamma dose rates continuously. Its measuring range is from natural background radiation (approximately 10 μR/h) to more than 30 R/h and is divided into eight warning levels. The actual level is reported on-line to centers in the respective federal state and also to the federal warning center. It is intended to provide information for immediate action after explosion of nuclear warheads when external radiation is of much concern. The stations are therefore in populated areas, and no information is possible on the situation in the mountains. The system is not coupled to meteorological systems, which is a drawback. Because no nuclide-specific data can be provided by this system, only the external doses to the population can be estimated.

Assessment

On the evening of 28 April information about a nuclear accident at Chernobyl was spread by Austrian radio and TV. Reliable information was obtained in the morning of 29 April from the radiation protection institutes of Finland and Sweden. As in the case of Switzerland the meteorological forecasts denied that air masses from Chernobyl would reach Austria in the following days. However, because information said that the reactor was burning, and therefore contamination was expected later, a first alarm was given. In the early afternoon a small but significant rise of dose rates was noticed in Vienna and northeast Austria, and fresh fission products were detected in high concentrations in Vienna and in Seibersdorf south of Vienna. As such the preparations for measurements became the first measurements. Actually all known models following the spread of the Chernobyl contamination have failed to give an explanation of why the first radioactive cloud came on 29 April from Czechoslovakia to Austria and eastern Bavaria (Weiss *et al.*, 1986). (This fact supports my view that even the best models and calculations cannot replace measurements.) Increasing air activities and local showers caused heavy contamination in areas in the south and southwest of Austria in the morning of April 30. A second cloud on the same day added contamination to the north and northwest of Austria.

The highest air contamination was measured on 30 April in Vienna, namely, 1.5 nCi/m^3 for aerosol-bound I-131 (55 Bq/m^3) and approximately 250 pCi/m^3 (9.3 Bq/m^3) for Cs-137. The highest deposition occurred on 1 May during heavy showers in Upper Austria. The map of precipitation shows fairly good agreement with data from the early warning system.

From data on aerosols it is evident that different parts of the country had been contaminated by different air masses at various times. Data from the early warning system showed extreme nonuniform contamination. No data on the mountains were available; even today the situation there is largely unknown, but it has been confirmed in several cases that contamination is increasing with sea level.

Dose rates exceeding natural background radiation varied in Austria from 10 to 260 μR/h on 1 May. The highest depositions measured in Upper Austria were in the range of more than 100 kBq/m^2. There is little doubt that deposition was higher in some mountain regions. It is very difficult to compare the contamination situation for different countries, but it seems that Austria was perhaps the most affected country in Western Europe. Obviously deposition was higher in some parts of Sweden, which causes more severe long-term problems, but the effect of contamination on the population depends on many parameters, of which initial deposition is only one.

The development of plants plays a very important role. The whole territory of Austria was more or less contaminated and for a rough comparison it can be mentioned that the lowest contaminated areas in Austria corresponded to the highest contaminated ones in the respective neighboring countries. In Austria the growing season had just started. The main production areas for milk, milk products, and meat were the ones most contaminated. Direct fallout on leafy vegetables like lettuce and spinach, on blossoms of many fruit trees, on newly emerged leaves, and on grass caused severe contamination of all foodstuff on a short-term scale. Direct fallout on the year's first harvest of hay also caused contamination on a long-term scale for milk, milk products, and meat until at least spring 1987.

Countermeasures by the authorities aimed to reduce the doses received by the population by first limiting the intake of I-131 via milk and milk products as well as by fresh vegetables. After this iodine phase, which lasted about one month until the I-131 had decayed, contamination by radiocesium became a real problem because a part of the food production exceeded the limits set by the authorities. Extensive monitoring of foodstuff in both the iodine and the cesium phase was necessary to establish a survey on both type of foodstuff and regional distribution. An appreciable amount of measuring had to be done because of public interest. Not all institutions that had the necessary equipment to perform measurements were able to handle the enormous amount of samples – not to mention the limited working capacity of personnel. Most stations had to introduce shift work, but even a 24-hour operation was not enough to measure all samples.

Samples were collected by local officials and transported mostly by the army to the laboratories. All governmental laboratories and the research institute in Seibersdorf were located in the eastern part of the country, and it took some time to establish a laboratory in Tyrol for local measurements of the western federal states. By end of 1986 an enormous amount of approximately 80,000 samples had been measured, and it is clear that not all were measured for radiation protection reasons.

Owing to the use of contaminated hay during the winter of 1986–1987 there was a pronounced rise of the radiocesium concentration in milk, milk products, and meat, which again made extensive assessment necessary. Since spring 1987, on the whole, all levels have decreased considerably. Foodstuff still of concern are mushrooms, which show radiocesium values close to or above the very strict limit of 3 nCi/kg (111 Bq/kg) with some species like *Xerocomus badius* showing extremely high values, and game in certain parts of the country.

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Chapter 3

Health Effects: Potential Long-Term Consequences in Europe

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The discovery of a new type of radiation by W.C. Röntgen in 1895, called X rays, was very soon followed by the publication of numerous papers describing the potential and actual applications of the new technique. Almost simultaneously with these early uses, the first observations on the harmful effects of radiation in the human body were also made. Alopecia, the loss of hair following X-ray photography, was reported in 1896, about four months after Röntgen's discovery. Other skin lesions were eloquently described by several authors about the same time. The earliest case of radiation-induced skin cancer was recorded in 1902 in a radiologist who had made X-ray diagnosis during the preceding years. As early as 1911, four cases of leukemia among radiologists were also reported and it was stated that long continued exposure to X rays might cause this disease. In the meantime, acute effects of radiation on internal organs including blood-forming tissues and the intestinal tract had also been observed.

The discovery of radioactivity by H. Becquerel one year later was also quickly followed by the use of radium in medicine, in research, and subsequently in the manufacture of luminous paints. The first casualty from overexposure to radium was Becquerel himself. Erythema and ulceration of the skin developed in the area under the vest pocket in which he carried a small radium preparation enclosed in a glass tube.

As a consequence of these observations and the growing clinical and industrial usage of radiation sources, the biological effects of radiation were widely studied in subsequent years.

3.1 Biological Effects of Radiation

The interaction of ionizing radiation with the human body, arising either from external sources outside the body or from internal contamination of the body by radioactive substances, leads to biological effects that may later show up as *clinical symptoms.* The nature and severity of these symptoms and the time at which they appear depend on the amount of radiation energy absorbed in the body and the rate at which it is received.

The effects of radiation on the human body are the result of damage to the individual cells. These effects may be conveniently divided into two classes, namely, *somatic* and *hereditary.* The somatic effects arise from damage of the ordinary cells of the body and affect only the irradiated person. The hereditary effects are due to damage to the germ cells in the reproductive organs – the gonads. The important difference is that, in the latter case, the damage manifests itself in the offspring of the irradiated person: children, grandchildren, and subsequent generations (Martin and Harbison, 1979).

3.1.1 Somatic effects of radiation

Early effects. Early radiation effects are those which occur in the period from a few hours up to a few weeks after receiving a large dose over a few hours or less. The effects are the results of major depletion of cell population in a number of body organs owing to cell killing and the prevention or delay of cell division.

The main effects are attributable to bone marrow, gastrointestinal, or neurovascular damage depending on the dose received. Very high doses, of the order of 100 grays (Gy), damage the central nervous system so badly that death may occur within hours or days. At doses of 10 to 50 Gy to the *whole body*, the victim may escape this fate only to die from gastrointestinal damage between one and two weeks later. Lower doses may avoid gastrointestinal injury – or permit recovery from it – but still cause death mainly from damage to the red bone marrow – the tissue that forms blood. The red bone marrow and the rest of the blood-forming system are among the most sensitive organs and are affected by as little as 0.5 to 1 Gy. Fortunately, they also have a remarkable capacity for regeneration and, if the dose is not so great as to overwhelm them, can completely recover. If *only part of the body* is irradiated, enough bone marrow will normally survive unimpaired to replace what is damaged.

Reproductive organs and eyes are also particularly sensitive.

Absorbed whole body doses above about 1 Gy give rise to acute radiation sickness manifesting itself in nausea and vomiting a few hours after the exposure. Absorbed doses above 2 Gy can lead to death within one or two months after exposure. There is no well-defined dose above which death is certain, but the chances of surviving a dose of about 8 Gy would be very low. Similarly, there is no well-defined threshold dose below which there is no risk of death, though below about 1.5 Gy the risk of early death would be very low. A reasonable estimate of the dose that would be lethal for 50% of the exposed subjects within 60 days after exposure, called $LD_{50/60}$, is thought to be about 3 Gy for a man. Such high doses could only be received in the event of a major radiation accident (UNEP, 1985).

Late effects. It became apparent in the early part of the twentieth century that certain individuals, such as radiologists and their patients, who were exposed to relatively high levels of radiation, showed a higher incidence of certain types of cancer than those not exposed to ionizing radiation. Later, detailed studies on populations exposed to radiation from atomic bombs, on patients subjected to radiation therapy, and on workers exposed to radiation on the job (particularly uranium miners) have confirmed the ability of radiation to induce cancer.

The estimation of the increased risk of cancer is complicated by the fact that radiation-induced cancers are not normally distinguishable from those which arise spontaneously. In addition, there is a long and variable latent period, from about 5 to 30 years or more, between exposure to radiation and the appearance of cancer. However, at the relatively high levels of exposure approximate estimates can be made by extrapolation from the risk at high dose levels to much lower levels on the assumption of a linear relationship between dose and risk. This assumption of a linear relationship forms the basis for the system of dose limitation recommended by the International Commission on Radiological Protection (ICRP, 1977; IAEA, 1982).

One implication of the assumption of a linear relationship between dose equivalent and cancer risk is that the same number of radiation-induced cancers would result from the same collective dose spread over a different size of population. A dose of 1 millisievert (mSv) to 1 million people represents a collective dose of 1,000 man-Sv. A collective dose of 1,000 man-Sv would also be expected if a dose of 0.1 mSv is received by each member of a population of 10 million people. On this convenient basis, it is possible to arrive at rough estimates of the risks for different types of cancer (Martin and Harbison, 1979).

Leukemia seems to be the first cancer to emerge in a population after irradiation. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimates that two people out of every thousand will die of leukemia for every Gy they receive.

Breast and thyroid cancers seem to be the most common tumors caused by radiation. About 10 people in every 1,000 will contract thyroid cancer, and 10 women in every 1,000 will contract breast cancer per Gy. But both cancers can commonly be cured, and radiation-induced thyroid cancers have particularly low mortality rates. So only about 5 women in every 1,000 are likely to die of breast cancer per Gy, and only 1 person in every 2,000 thousand is expected to die of thyroid cancer.

Lung cancer, in contrast, is fatal. It is also a common cancer in irradiated populations, and 2 persons out of every 1,000 may die from lung cancer for every Gy in a group of people representing all ages. Other cancers seem to be less readily induced by radiation.

Children are more vulnerable than adults, and babies in the uterus may be more vulnerable still (UNEP, 1985).

Prenatal radiation effects. Prenatal mortality as well as malformation (i.e., developmental abnormality) and growth disturbances may also result from exposure to ionizing radiation in the uterus. UNSCEAR (1988) has estimated that a dose to the conceptus of 0.01 Gy delivered over the whole pregnancy would add a probability of adverse health effects in the live-born of less than 0.002. The normal risk of a nonirradiated live-born having the same conditions is about 0.06 (6%).

Mental retardation is the most likely type of developmental abnormality to appear in the human species. The probability of radiation-related mental retardation is essentially zero before the eighth week and after the twenty-fifth week of fetal development; it is maximum between the eighth and fifteenth weeks, and decreases between the sixteenth and the twenty-fifth weeks (UNSCEAR, 1988).

The dosimetric data suggest a linear relationship between risk of severe mental retardation and dose received between the eighth and the fifteenth weeks. The risk is 1 in 2,500 for each mGy, and a threshold of 100 to 250 milligray cannot be excluded below which there is no effect. For the time from the sixteenth to the twenty-fifth week after conception, the risk is about 1 in 10,000 for each mGy, and the dose effect relationship is consistent with the likelihood of a threshold at about 700 mGy.

Though the individual risks are high, and the effects of the damage are particularly distressing, the number of women at that particular stage of pregnancy at any one time is only a small proportion of the population. In addition, the existence of thresholds would effectively ensure that severe mental retardation would not result from environmental exposures to the public except for the direct vicinity of a severe radiation accident (Pochin, 1988).

3.1.2 Hereditary effects of radiation

The hereditary effects of radiation result from damage to the reproductive cells. This damage takes the form of alterations known as genetic mutations in the hereditary material of the cell. Spontaneous mutation accounts for the fact that an appreciable fraction, about 10% of the world's population, suffers from 1 of the 500 or more defects or diseases attributed to hereditary disorders.

Radiation can induce gene mutations in living organisms, which are indistinguishable from naturally occurring mutations. It is generally assumed that all mutations are harmful, although this is not necessarily true since the human species has attained its present advanced state via a series of mutations. Because ionizing radiation can cause an increase in the mutation rate, its use may increase the number of genetically abnormal people in future generations (Martin and Harbison, 1979).

There is extremely little information on the genetic effects of radiation on humans. In the absence of human data, the risks of hereditary defects have been estimated on the basis of extensive studies on animals. UNSCEAR estimated the risk of serious hereditary ill health within the first two generations following the irradiation of either parent to be from 0 to 12 per million mSv. Over all generations, the risk would be about four times this value. Clearly, only that exposure which occurs up to the time of conception can affect the genetic characteristics of the offspring; since the mean age of childbearing is about 30 years, only a small proportion of the dose received by a typical population will be genetically harmful. The total genetic risk in all generations averaged over both sexes and over all ages is therefore between 0 and 20 serious effects per million mSv (UNSCEAR, 1988).

3.1.3 Stochastic and nonstochastic effects

Recently, another classification of radiation effects has been introduced by the International Commission on Radiological Protection (ICRP) to distinguish between effects which depend on the probability of occurrence and those which are related to the severity of the dose. The former categories are stochastic effects, and the latter nonstochastic effects.

Stochastic effects are those for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose, without threshold. The term stochastic can best be understood by considering it to refer to effects that either occur or do not occur. Thus cancer induction is a stochastic effect.

The probability of a radiation-induced cancer of a particular type depends on the dose received. Hereditary effects are also regarded as being stochastic.

Nonstochastic effects are those for which the severity of the effect varies with the dose, and for which a threshold may therefore exist. Examples of nonstochastic effects are the early effects of radiation – damage to blood vessels, cataracts, and impairment of fertility. The severity of these effects varies with the amount of the radiation dose received, but it is not detectable at all unless a threshold dose is exceeded (IAEA, 1982).

3.2 Radiation Protection Principles

3.2.1 Control of exposure under normal conditions

The aim of radiation protection, as stated by ICRP, should be to prevent detrimental nonstochastic effects and to limit the probability of stochastic effects to levels deemed to be acceptable. The aim is achieved by the following:

- Setting dose equivalent limits at levels that are sufficiently low to ensure that no threshold dose is reached over the course of an individual's lifetime – *prevention of nonstochastic effects.*
- Keeping all justifiable exposures as low as reasonably achievable, taking into account economic and social factors, subject always to the boundary conditions that the appropriate effective dose equivalent limit shall not be exceeded – *limitation of stochastic effects.*

To prevent nonstochastic effects in individual members of the public, a dose equivalent limit of 50 mSv in a year is recommended for all tissues and organs.

To limit stochastic effects, the annual dose equivalent limit for uniform irradiation of the whole body is set at 5 mSv. For nonuniform irradiation of the body, weighting factors have been assigned to the various individual organs, relative to the whole body as one, reflecting the harm attributable to irradiation of each organ (Martin and Harbison, 1979). The sum of the dose equivalents in individual organs, each weighted by the appropriate organ weighting factor (see Appendix at the back of the book), is the effective dose equivalent (IAEA, 1982). The effective dose equivalent limit so calculated was originally recommended by ICRP to be 5 mSv in a year (ICRP, 1977).

At the ICRP 1985 Paris meeting, however, it was stated that 1 mSv in a year is the principal limit of dose for members of the public (ICRP, 1985). It is permissible to increase the annual dose limit to 5 mSv for a few years, provided that the average annual effective dose equivalent over a lifetime does not exceed the principal limit of 1 mSv per year.

Table 3.1. Intervention levels for protective measures in the early and intermediate phases of a major nuclear accident.

	Dose equivalent (mSv)	
Protective measure	Whole body	Thyroid, lung, or any single organ preferentially irradiated
Early Phase		
Sheltering	5–50	50–500
Stable iodine prophylaxis	–	50–500
Evacuation	50–500	500–5000
Intermediate Phase		
Control of foodstuffs and drinking water	5–50[a]	50–500[a]
Relocation	50–500[a]	Not expected

[a] Dose equivalent committed in the first post-accident year.

3.2.2 Abnormal exposure due to the accident

To limit exposure of the general public following an accidental release of radioactive substances into the environment, remedial actions or interventions can only be introduced. It is not possible to recommend general levels of dose that would be appropriate for application in all accidental circumstances to undertake interventions. All interventions or countermeasures that can be applied to reduce the exposure to members of the public following an accidental release of radioactive materials carry some detriment to the people concerned. Thus, the decision to introduce countermeasures (i.e., make an intervention) must be based on a balance of the detriment that they carry and the reduction in the exposure that they are likely to achieve.

However, ICRP judges that it might be possible to set levels below which intervention would not generally be considered to be justified and similarly to set dose levels above which intervention is almost obligatory. Intervention levels should be included in the emergency plan of each facility, and should be reassessed in the light of the available information at the time of intervention in the real accident situation (Martin and Harbison, 1979).

For emergency planning three consecutive time phases are usually identified that are common to all major nuclear accidents: early, intermediate, and late or recovery phases. Numerical guidance for the introduction of protective countermeasures in the early and intermediate phases is given by the ICRP and other competent international organizations, such as the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO). The guidance is summarized in *Table 3.1*, and is expressed in terms of dose ranges corresponding to each protective measure (ICRP, 1984; IAEA, 1985; WHO, 1984; WHO, 1987a).

Table 3.2. Core inventories and total releases.

Element	Half-life (d)	Inventory[a] (Bq)	Percentage released
Kr-85	3,930	3.3×10^{16}	~100
Xe-133	5.27	1.7×10^{18}	~100
I-131	8.05	1.3×10^{18}	20
Te-132	3.25	3.2×10^{17}	15
Cs-134	750	1.9×10^{17}	10
Cs-137	1.1×10^{4}	2.9×10^{17}	13
Mo-99	2.8	4.8×10^{18}	2.3
Zr-95	65.5	4.4×10^{18}	3.2
Ru-103	39.5	4.1×10^{18}	2.9
Ru-106	368	2.0×10^{18}	2.9
Ba-140	12.8	2.9×10^{18}	5.6
Ce-141	32.5	4.4×10^{18}	2.3
Ce-144	284	3.2×10^{18}	2.8
Sr-89	53	2.0×10^{18}	4
Sr-90	1.02×10^{4}	2.0×10^{17}	4
Np-239	2.35	1.4×10^{17}	3
Pu-238	3.15×10^{4}	1.0×10^{15}	3
Pu-239	8.9×10^{6}	8.5×10^{14}	3
Pu-240	2.4×10^{6}	1.2×10^{15}	3
Pu-241	4,800	1.7×10^{17}	3
Cm-242	164	2.6×10^{16}	3

[a] Decay corrected to 6 May 1986 and calculated as prescribed by Soviet experts. (Source: IAEA, 1986.)

3.3 Impact of the Chernobyl Accident on Europe's Population

3.3.1 Release and dispersion of radionuclides

The accident at the Chernobyl nuclear power station was one of the most serious nuclear accident that has ever occurred. Large amounts of radioactive materials were released into the environment and vast territories inside and outside the USSR were contaminated.

The large amounts of radioactive substances released were carried away in the form of gas and dust particles by air currents. The release did not occur in a single event. Only about 25% of the material was released during the first day of the accident; the rest escaped during the next nine days. The core inventory of radionuclides and its estimated percentage released are shown in *Table 3.2*.

The initial explosions and the heat from the fires that followed carried the radioactive materials to a height of about 1.5 km where they were transported by the wind along the western parts of the USSR toward Finland and Scandinavia. First arrival of radioactive materials outside the USSR was detected in Sweden on 27 April.

A portion of the initial plume at a lower altitude was directed southward to Poland and the German Democratic Republic. Other Eastern and Central European countries were affected on 29 and 30 April. Radioactive air masses entered northern Italy during the night of 29 and 30 April and arrived at the central and southern parts of the country on the following day. Detectable activity reached France, Belgium, and the Netherlands on 1 May, the United Kingdom on 2 May, and Greece on 2 and 3 May. Long-range atmospheric transport spread the released radioactivity throughout the Northern Hemisphere during the first week of May.

Extensive national monitoring programs were initiated in all countries following the Chernobyl accident to determine the extent and degree of contamination from the radionuclides released and to evaluate the need for implementing various countermeasures. These measurements of the environmental radiation levels and concentrations of radioactive substances in air, soil, and diet and in the human body provided the basis for the evaluation of radiation exposure by national authorities and competent international organizations such as the International Atomic Energy Agency, the UN Scientific Committee on the Effects of Atomic Radiation, and the World Health Organization (IAEA, 1986; UNSCEAR, 1988; WHO, 1986 and 1987b; ISH for WHO, 1987).

Radionuclides considered. Radionuclides identified in air by gamma spectrometry indicated a prevalence of volatile radionuclides, such as I-131, I-132, Te-132, Cs-134, Cs-136, and Cs-137, as compared with nonvolatile ones, such as Mo-99, Zr/Nb-95, Ru-103, Ru-106, Ba/La-140, Ce-141, and Ce-144. Other radionuclides sporadically detected in air or rainwater by beta or alpha spectrometry were Sr-89, Sr-90, H-3, Pu-238, Pu-239, Pu-240, and Cm-242.

The composition of iodine activity in air was shown to be aerosol, elemental gaseous form and organically bound. The ratio of these fractions changed from place to place and with time.

Critical exposure pathways. Two major exposure pathways were considered in the dose assessments after the nuclear accident:

(1) External irradiation from radioactive materials deposited on the ground.
(2) Ingestion of foodstuffs contaminated with radioactive substances.

Two additional minor pathways were also considered:

(3) External gamma irradiation from radioactive materials present in the cloud.
(4) Inhalation of radionuclides during passage of the cloud.

The pathways of cloud gamma exposure and inhalation of radionuclides were effective for only the short period before deposition of the airborne material. Exposure along the other two pathways continued according to the half-lives of the radionuclides: several days for I-131 and several years for Cs-137.

Deposition of radionuclides. Deposition of radioactive materials was associated mainly with rainfall. Rainfall occurred very sporadically throughout the European continent during the contaminated air passage. Therefore, the deposition pattern was very irregular. Where the plume passed and there was no rainfall, cesium deposition was significantly less than that of iodine. Where it rained through the plume, iodine deposition was higher and cesium deposition was similar to that of iodine. The median value for all countries of the ratio of I-131 radionuclide deposition to Cs-137 was about five.

Highest deposition of Cs-137 outside the USSR was recorded in Sweden north of Stockholm. Average values of deposition density greater than 5 kBq/m^2 for the entire country were recorded in Austria, the GDR, Poland, and Yugoslavia, and less than 5 kBq/m^2 were indicated for the other European countries.

In the first month after initial deposition, a number of short-lived radionuclides contributed significantly to the external exposure rate, including Te-132, I-132, I-131, Ba/La-140, Ru-103, and Ru-106.

Radionuclides of importance to the external gamma irradiation dose from deposited materials beyond the first month include Cs-134, Cs-137, Ru-103, and Ru-106. In the long term, external irradiation is due primarily to Cs-134 and Cs-137. Deposition of I-131, Cs-134, and Cs-137 is important in determining doses from the ingestion pathway.

3.3.2 Exposures to European populations

Calculations have been performed and the results published by many European countries on exposures of their populations to radionuclides released during the accident (e.g., Sztanyik *et al.*, 1987). In addition, several regional and international organizations, such as the European Community, the Organisation for Economic Co-operation and Development/Nuclear Energy Agency, the United Nations Scientific Committee on the Effects of Atomic Radiation, and the World Health Organization, have also made such assessments for the countries for which measurement results have been made available (ISH for WHO, 1987; WHO, 1987b; Morrey *et al.*, 1987; OECD/NEA, 1987).

First year committed effective dose equivalents. The estimates of the committed effective dose equivalents to individuals during the first year after the

Table 3.3. Average first year effective dose equivalent in the European countries.

Country	Dose range (μSv)
Austria, Bulgaria, Greece, Romania	500–750
Czechoslovakia, Finland, Italy, Poland, Switzerland, Yugoslavia	250–500
Federal Republic of Germany, German Democratic Republic, Hungary, Ireland, Norway, Sweden	100–250
Belgium, Denmark, France, Luxembourg, Netherlands, Portugal, Spain, UK	<100
Overall average	200

(Source: UNSCEAR, 1988.)

accident in Europe were the highest in Austria, Bulgaria, Greece, and Romania, followed by other countries in Central and Southeastern Europe. Countries farther to the west were less affected in accordance with the deposition pattern (*Table 3.3*).

In each country there were more localized areas where both higher and lower exposures were received than the calculated average. Regions with first year committed effective dose equivalents ranging from 1 to 2 mSv were located in Romania and Switzerland, and from 0.5 to 1 mSv in Austria, Bulgaria, the Federal Republic of Germany, Greece, and Yugoslavia. These estimates of the UNSCEAR are in reasonable agreement with those reported separately by the individual countries. Discrepancies with country results can be attributed to averaging measurement results over large subregions and to using somewhat different assumptions for occupancy, shielding, urban runoff, and food consumption.

Thyroid dose equivalents. Thyroid dose equivalents have been evaluated specifically because of the significant amounts of I-131 in the released materials. These doses have generally been higher to infants than to adults, owing to the importance of the main pathway through milk consumption, greater I-131 uptake, and smaller thyroid mass.

The estimated average infant (one-year-old) and adult thyroid dose equivalents during the first year are primarily due to I-131. However, contributions from other radionuclides and all pathways have also been taken into account. The effects of countermeasures have been considered in the results insofar as such actions were reflected in integrated concentrations in food.

The country averages of infant thyroid dose equivalents in most European countries have been in the range of 1 to 20 mSv. Adult thyroid doses are usually less than infant doses in the same country by a factor of about five in Central and Western Europe, but the differences are less in Northern Europe where concentration of radioiodine in milk was relatively low because cows

Table 3.4. First year thyroid dose equivalent in countries and subregions (mSv).

Region	Infants	Adults
Northern Europe (Denmark, Finland, Norway, Sweden)	0.15–1.8	0.06–1.2
Central Europe (Austria, Czechoslovakia, FRG, GDR, Hungary, Poland, Romania, Switzerland)	1.7–18	0.4–2.8
Western Europe (Belgium, France, Ireland, Luxembourg, Netherlands, UK)	0.7–2.7	0.1–0.6
Southern Europe (Bulgaria, Greece, Italy, Portugal, Spain, Yugoslavia)	<0.01–25	<0.01–5.5

(Source: UNSCEAR, 1988.)

were not grazing on pastures and in Southern Europe where contamination of leafy vegetables increased adult thyroid doses (*Table 3.4*).

UNSCEAR has not considered the use of thyroid blocking agents, although these would have afforded some additional protection against inhaled radioiodine. Since the contribution of this pathway to the thyroid dose was small, this neglect is not significant.

3.3.3 Collective effective dose equivalent commitment from the accident

Estimates of the collective effective dose equivalent commitment can be made for all countries based on detailed measurement data reported by the countries, or on the average distance of each country from the release point and the relationship of Cs-137 deposition density with distance. The total collective effective dose equivalent commitment for the population of the European continent from the accident is estimated by UNSCEAR to be about 556,000 man-Sv, of which 226,000 man-Sv (40.6%) is incurred by the population of the Soviet Union and 330,000 man-Sv (59.4%) by that of the other European countries.

3.3.4 Risks to health

The possible health consequences of radiation doses delivered after the Chernobyl accident may only be expressed in terms of stochastic effects. These stochastic health effects are fatal cancers, serious genetically related ill health, and possible teratogenic effects. They are superimposed on the *spontaneous* occurrence of the same diseases in the population. The radiation doses to individuals for the first year after the Chernobyl accident, as well as the committed collective doses projected for 50 years (i.e., future exposures), have been considered to assess the risk of possible health effects.

For fatal cancers induced by radiation, a risk factor of $2 \times 10^{-2}\text{Sv}^{-1}$ is used (e.g., if 100 individuals received 1 Sv of dose, a lifetime expectation of two fatal cancers is predicted). For serious genetic health effects, the appropriate risk factor is $4 \times 10^{-3}\text{Sv}^{-1}$ for the first two generations. Teratogenic effects, by all probability, may be seen following high radiation doses, and present knowledge does not exclude the possibility of a threshold, especially for low doses, in the range of less than 100 mSv. At higher doses the risk of severe mental retardation (a specific teratogenic effect) is 0.4 Sv^{-1} for a fetus exposed in the period from the eighth to the fifteenth week of gestation and 0.1 Sv^{-1} for a fetus exposed during the period from the sixteenth to the twenty-fifth week. Although low individual doses are considered here, these factors have been used in the calculations, which will give a conservative estimate of risk.

Concerning the health effects, the 50-year collective dose is about 0.33×10^6man-Sv. Thus, the upper estimate of associated fatal cancer cases is about $0.02 \times 0.33 \times 10^6 = 6{,}500$, which would be added to a normal expectation of about 96 million fatal cancers (assuming 20% is the fraction of overall spontaneous mortality due to cancer that is applied to the cohort of 480 million Europeans excluding the USSR). This is equivalent to an additional incidence of up to about 0.007%. Of the 6,500 fatal cancer cases, about 300 cases can be attributed to thyroid cancer. In addition, about 5,700 nonfatal thyroid cancer and 18,000 benign nodules can also be expected to be diagnosed.

Assuming 24×10^6 cases as a nominal incidence of serious genetic health disorders in the first generation, the additional radiation-induced effects are estimated at up to 650 cases (an extra 0.004%).

The expected number of livebirths in Europe is 12,000 for each million in a year, or a total of 5.8 million. The average individual dose in the first year is 0.2 mSv, and this is combined with risk factors for severe mental retardation of 0.4 for eight weeks (8/52 weeks) plus 0.1 for ten weeks (10/52 weeks). Up to an additional 100 cases might therefore be added to the 50,000 cases which would be expected spontaneously (an additional 0.2%).

The projected 6,500 anticipated radiation-induced cancer fatalities will not be evenly distributed throughout Europe (excluding the USSR). The risk of such fatalities will be higher in areas where deposition was higher or doses were greater. Because of differences in population density in these areas, radiation-induced cancer fatalities may be a higher proportion of the normal incidence than is given for Europe as a whole. Clearly, the reverse is also true.

The estimated range of radiation-induced increments in the possible stochastic effects is very low and possibly could not be detected, even by the most careful study (WHO, 1987b).

3.4 Conclusions

- Although the accident at the Chernobyl nuclear power plant in 1986 was a very serious event and the whole population of Europe has since been exposed to its radioactive emissions, the magnitude of radiation exposure has not been great.
- According to the best available estimate, the first year effective dose equivalent received by individuals might have been about 0.2 mSv on average, which is less than 10% of the dose received annually from natural environmental sources.
- The collective effective dose equivalent commitment of the European population (excluding the USSR) resulting from the Chernobyl accident might lead to additional incidents of fatal cancer, hereditary diseases, and severe mental retardations. These additional radiation-induced cases, however, would amount to such a low number that they could not be detected above the spontaneously occurring cases even by the most sensitive and careful studies.
- This assessment of radiation exposures from the Chernobyl accident has only considered the major radionuclides and exposure pathways that have contributed significantly to the individual and collective doses. Contributions of less important radionuclides and exposure pathways are also the subject of studies in various countries, but these studies should not considerably change the general conclusions of the accident's consequences.
- The sensitivity with which radiation and radioactive materials can be detected in the environment has resulted in some countries in overvaluation of measurement data, exaggeration of potential danger to health, and overreaction of national authorities in regard to the introduction of protective measures in the early post-accident period.
- Preparedness of competent authorities to organize environmental surveillance and monitoring of foodstuffs and people, to make fast and realistic evaluations of measurement data, and to decide on protective measures, if needed, as well as to inform the public and media of all aspects of risk involved in radiation accidents are the most important prerequisites to avoid anxiety and panic among the population under such circumstances.

Addendum

Some preliminary results of the epidemiological studies performed on the health consequences of the Chernobyl accident were published after the completion of this chapter. These deserve attention and are, therefore, summarized briefly below.

The widespread radioactive contamination of the environment following the Chernobyl accident has generated considerable public concern with regard to possible adverse health effects in the exposed populations. A number of people, among them even some health professionals, were afraid of increases in spontaneous abortions and congenital malformations and increases in cancer rates, especially leukemia. Early dose estimates suggested that – apart from a limited area surrounding the accident site – such adverse health effects might be at a level too low to be detectable against variations in their background incidence. Nevertheless, health authorities in several European countries initiated epidemiological studies to monitor the possible health implications of the accident.

In January 1987, a cluster of ten cases of trisomy 21 (frequently associated with Down's syndrome) was reported in births in West Berlin, nine months after the Chernobyl accident. Therefore, chromosomal anomaly syndromes recorded in 18 EUROCAT registries from January 1986 to March 1987 in livebirths, stillbirths, and induced abortions were specially reviewed. (EUROCAT, the European Registries of Congenital Abnormalities and Twins, is a concerted action of the European Communities for the epidemiological surveillance of congenital anomalies. It comprises 23 centers in 12 countries of Western Europe, and studies more than 0.3 million births per year.) A comparison of children conceived before 1 May 1986 with those conceived after the accident did not indicate any significant increase in the frequency rates of trisomy 21 and other trisomies (EEMS, 1987).

The WHO Regional Office for Europe held a consultation on epidemiology related to the Chernobyl accident in Copenhagen, 13 and 14 May 1987. At this meeting, information of the radiological consequences of the accident for the population of the European part of the USSR was also updated. It was reported that up to the date of the meeting, 21 children were born to fathers who had been irradiated as a result of the Chernobyl accident. All children appeared normal. Some women living in the area around Chernobyl requested abortions following the accident. Their abortuses were not malformed (WHO, 1987c).

The monthly statistics on pregnancy outcomes, such as induced abortions, fetal deaths, birth weight under 2,500 g, and various congenital anomalies including Down's syndrome, were evaluated in Hungary after the Chernobyl accident up to 31 March 1987. Only a somewhat higher rate (10%) of newborns with birth weights under 2,500 g in May and June 1986 was detected. It may, perhaps, be attributed to some cases of premature childbirth caused by psychosocial anxiety (Czeizel and Billege, 1987).

A preliminary evaluation of the impact on the Chernobyl accident of the frequency of central nervous system malformations and eye defects in livebirths, stillbirths, and induced abortions up to June 1987 was published by the EUROCAT Working Group in 1988. Eighteen registries in nine countries (Belgium, Denmark, France, Ireland, Italy, Luxembourg, Malta, United Kingdom, and Yugoslavia) were able to supply all the necessary information. Observed frequencies of the six classes of anomaly in the exposed cohorts were compared with expected frequencies calculated from baseline rates for the period of 1980–1985. Mental retardation could not be considered since it is not identifiable at birth, except insofar as it is correlated with microcephaly.

The results do not show an increase in the frequency of malformations in the countries of Western Europe. The only significant increase was in neural tube defects in Odense, Denmark (four cases were observed in a cohort where 0.9 were expected). It should be mentioned, however, that Denmark did not belong to the heavily contaminated areas of Europe. According to the conclusions of the Working Group, the evidence presented indicates that in the regions studied termination of pregnancies or invasive prenatal diagnostic examinations were not justified for women exposed during pregnancy (EUROCAT Working Group, 1988).

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Chapter 4

Agriculture and Trade

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This chapter describes the responses of governments to the fallout, particularly with respect to the contamination of food and the effect of governmental decisions on agriculture and trade. To put the subsequent description of events in perspective, it is prefaced with a brief explanation of how permitted levels of radiation in food can be derived from radiation dose recommendations. Although much of this work was done after Chernobyl, it is one of several possible systematic calculation methods, a knowledge of which allows a better understanding of the limits adopted under the pressure of events.

4.1 Derived Reference Levels for Radioactivity in Foods

Before Chernobyl no credence had been given to the possibility that a single reactor accident could contaminate agricultural crops on a national, let alone a continental, scale. Plans, developed by countries operating nuclear reactors or facilities, were based on the assumption that the consequences of an accident would be localized. The control of the radiation dose to the general public would therefore be carried out by means of various specific local countermeasures that would be taken on the basis of detailed monitoring information from the area.

Very few countries had established contamination limits for foodstuffs in trade, the most notable exception being the US Food and Drug Administration (USFDA, 1982), which had defined protective action guidelines in 1982. These were set up with domestic nuclear incidents in mind and are basic rules for interactive control that give instructions to officials and authorities on how to deal with contaminated food on the basis of comprehensive monitoring information.

Using these guidelines as a starting point, the FDA on 15 May 1986 set "action levels" for imported foods, above which the FDA has discretion to act. They had been calculated on the assumption that all food being eaten by the population was contaminated to these levels. They were therefore intended not as countermeasures to control dose, but as legal levels above which there was discretion for the FDA to take regulatory action, and below which traders would have legal certainty that the food would be considered safe for consumption. In practice, no foods exceeding these discretionary limits were allowed to enter the USA.

Food law in most countries is based on the premise that food must be safe, and it is illegal to add any nonfood substance to food unless expressly permitted. It is also illegal to allow it to become contaminated, particularly where the contaminant is injurious to human health. Unavoidable contamination by such substances as natural toxins (e.g., aflatoxins in groundnuts) is usually regulated by setting targets and applying the "as low as reasonably achievable" (ALARA) approach.

Natural radioactivity occurs in foodstuffs mainly in the form of potassium 40 (K-40) and carbon 14 (C-14), the amounts of these substances present in food and in the human body being a function of their natural occurrence. For example, every gram of potassium contains about 30 Bq of K-40. No purpose would be served by setting limits for these isotopes, since there is no practical way of affecting their presence in food, nor ultimately in the human body. (The average K-40 concentration in the human body is about 80 Bq/kg.)

To set limits in a case where food contamination was unavoidable, it was necessary to develop a new approach that joined the traditional method of determining contamination of foodstuffs with nonradioactive contaminants with that used in radiological protection. This new approach led to the development of the concept of *Derived Reference Levels* (DRLs), so called because they are derived from the levels of radiation dose such as the committed effective dose equivalent to the general population following a nuclear accident of 5 millisievert (mSv) recommended by the International Commission for Radiological Protection (ICRP). This will be referred to below as the ICRP recommendation (ICRP, 1982).

The European Atomic Energy (EURATOM) Treaty provides for the fixing of radiation protection standards taking into account the advice from a specialist committee, the Article 31 Committee. At the request of the Commission of the European Communities (CEC), the EURATOM Article 31 Committee began to develop a method of calculation of DRLs soon after Chernobyl.

The starting point for these calculations was a two-tier system of radiation dose reference levels, namely:

(1) A lower level below which countermeasures are not warranted on radiological protection grounds.
(2) An upper level representing the limit, the transgression of which should be avoided by the introduction of countermeasures.

Between the two levels there is scope for judgment by control authorities.

The lower level of 5 mSv was used for the effective dose based on the ICRP recommendation and an upper level of 50 mSv; for singly irradiated organs, such as the thyroid, the respective values are 10 times higher.

These dose levels were translated into corresponding contamination levels in foodstuffs (DRLs) expressed in Bq/kg. This required consideration of the following:

- The radiologically important radionuclides.
- The radiation dose produced by these radionuclides in the human body.
- Their metabolic behavior in the body.
- The pattern of food consumption for all groups of the population (which foods and how much).
- The diversity of sources of the food supply.
- The levels of the relevant radionuclides in these foods, DRLs.

The following simplifications were made:

- Seventeen radionuclides of potential health significance following an accidental release of radioactivity from a reactor or other nuclear installation were identified.
- Three representative age ranges were used for the calculation: the 1-year-old infant, the 10-year-old child, and the adult.
- The diet was broken down into five components: dairy products, meat, cereals, fruits and vegetables, and drinking water. For each age range, a typical community diet has been established in terms of these five components.

The calculated DRLs do not apply to foodstuff contamination in the area near the accident, but apply only to widespread contamination. In the latter case, it will be impossible for an individual to consume food that is contaminated at the DRL for a whole year. The diet diversity factor was judged to be equivalent to the consumption of 10% of each dietary component, contaminated to the full value of the DRL for the whole of one year.

Only in the case of the iodine isotopes was the additivity of the doses from the various dietary components not taken into account. For these short-lived isotopes, radiation exposure will last for a very small part of the year giving a large supplementary safety factor. On this basis, the DRLs corresponding to the lower dose reference levels were calculated for each radionuclide, each age range, and each dietary component.

To produce a more manageable system, the radionuclides were grouped into three categories: iodine and strontium, alpha emitters, and all other radionuclides with a half-life of more than 10 days. The DRL value selected in each case was that corresponding to the most restrictive radionuclides for the food group concerned. As an exception to this rule for the subgroup all other nuclides in milk products, the cesium value was chosen, since other more restrictive radionuclides have a very low transfer factor from vegetation through the animal into milk.

It was concluded that adequate allowance has been made for additivity of the contribution from different radionuclides both within and between nuclide groups for the following reasons:

- The DRL for each nuclide group was calculated on the basis that the total activity of nuclides in the group is compared with the limiting value for the radionuclide in the group that is the most radiotoxic toward the most sensitive age range.
- Reference levels for iodine isotopes were based on the dose to the thyroid; their contribution to the effective dose equivalent is therefore reduced.
- In an accident, it is unlikely that nuclides from all the three groups will be present in significant amounts in the food chain.

Preliminary DRLs were established in November 1986 and were further refined; the results are shown in *Table 4.1*.

The scientists chose assumptions with relatively large built-in safety factors that are sequential and therefore multiplicative. In addition, authorities applying the DRLs always use the lower DRL and introduce further safety factors. Thus, the probability of any individual exceeding the dose on which even the lower DRL was based is exceedingly small.

The major function of the DRLs when embodied as strict limits in legislation is to provide unequivocal contamination limits. The adherence to these limits assures consumers that radiation doses are not excessive and traders that food conforming to these limits can be sold.

4.2 Reaction of the European Community

The plume of contamination from Chernobyl moved toward Scandinavia within three days after the accident, *Figure 4.1*. The countries immediately affected responded, but it was several days before I-131 reached its peak in milk. The

Table 4.1. Derived reference levels (DRLs) as a basis for the control of food following a nuclear accidents.

Nuclide	Milk products	Other foodstuffs	Drinking water
Iodine and Strontium notably I-131, Sr-90	500	3,000	400
Plutonium and Transplutonium notably Pu-239, Am-24	20	80	10
All other nuclides with half-life > 10 days notably Cs-134, Cs-137	4,000	5,000	800

process of gathering and assessing data takes time, so the full extent of the fallout could not be recognized immediately.

Under the terms of the EURATOM Treaty, the CEC required environmental-monitoring data to be communicated to it from the Member States. This request met with limited success since the system was designed for long timescale reporting and not for dealing with nuclear accidents or emergency situations.

The food division (III-B-2) of the CEC had been operating a rapid alert system for food contamination for a number of years. This system links nominated officials responsible for food control in each EC Member State with a nominated official in the CEC. This official acts as an incident coordinator; data are transmitted to the Commission to be electronically recorded and, after control, retransmitted to the coordinating officials in the EC Member States. Where incidents are extensive or pose special problems, meetings of national coordinators are called in Brussels. On the basis of these consultations, such actions as the setting up of analytical methods or the setting of legal limits for contaminants can be initiated. The system handles several cases of widespread food contamination every year and was therefore well prepared at the time of Chernobyl – particularly following such extensive incidents as the contamination of Austrian wine by diethylene glycol, where more than 10,000 analyses were reported through it.

Following the receipt of information on radioactive fallout in Denmark and Sweden the CEC coordinator initiated the alert and attempted to call an immediate meeting. May 1, however, and in many countries May 2 were public holidays immediately preceding a weekend, when the closure of many government departments made it impossible to get all the participants to Brussels before Monday, May 5. Not only national food contamination controllers but also radiobiological experts and trade experts were invited to ensure that all aspects of the accident could be examined and the appropriate Community action initiated.

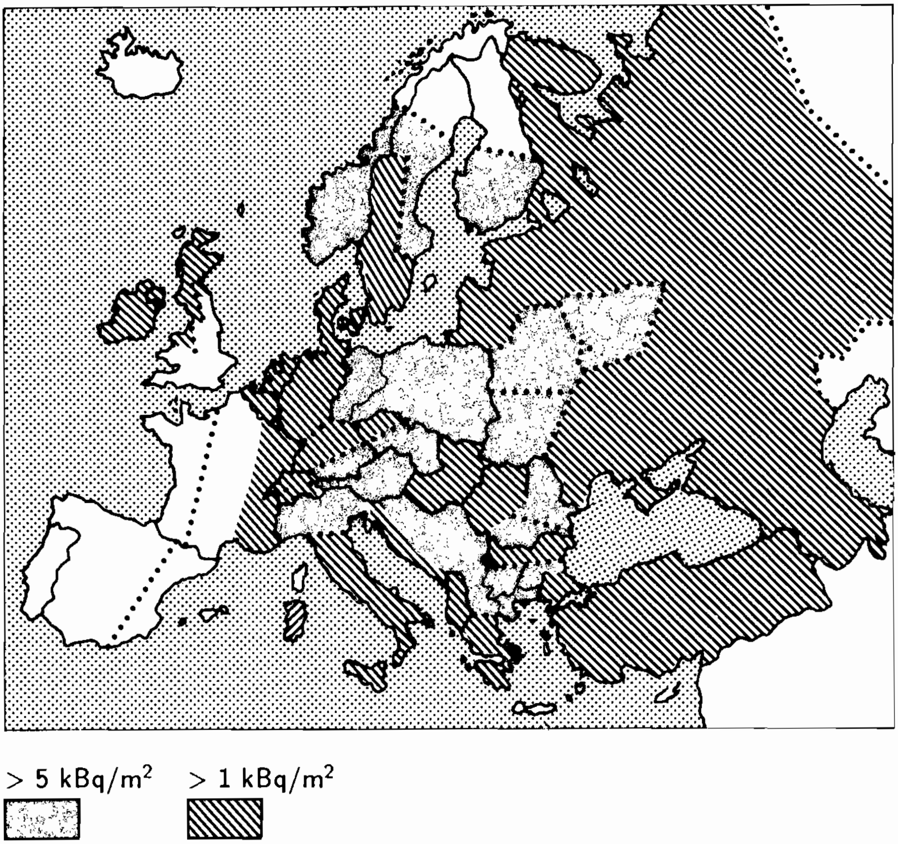

Figure 4.1. Average Cs-137 deposition density in countries or large subregions in Europe.

As the contaminated airstream moved westward, national and even local authorities began to take various countermeasures. These ranged from advice on prohibiting animals from grazing on pasture and infants from consuming dairy products to the banning of some foods and even the destruction of crops. A summary of these measures is set out in *Table 4.2*.

Trade in foodstuffs was inhibited by new border formalities (e.g., requirements for radioactivity certificates by Italy), and all EC countries had bans, severe restrictions, certification, or special examination requirements on food coming from the USSR and its neighboring countries. Even by the date of the meeting, a fully comprehensive picture of fallout and food contamination was not available. In some parts of Europe, the first fallout had only occurred on May 3, and in others the peak had not yet been attained. I-131 was still

Table 4.2. Countermeasures taken by European countries.

Countermeasure	Country
Evacuation, rehousing	USSR
Sheltering	Poland, USSR
Distribution of iodine tablets	Poland, USSR
Control or restriction of dairy products	Austria, Belgium, Bulgaria, Czeckoslovakia, Finland, Greece, Netherlands, Poland, Romania, Sweden, Switzerland, USSR, Yugoslavia
Advice not to drink rainwater	Austria, Federal Republic of Germany, Italy, Netherlands, Spain, Sweden, Switzerland, UK, Yugoslavia
Ban on sale of fresh vegetables	Austria, Bulgaria, France, Federal Republic of Germany, Greece, Italy, Netherlands, USSR
Advice not to eat fresh vegetables	Austria, Bulgaria, Italy, Sweden, Switzerland, Yugoslavia
Advice to wash fresh vegetables	Austria, Belgium, Denmark, Greece, Hungary, Netherlands, Switzerland, Yugoslavia
Restriction or ban on game	Greece, Federal Republic of Germany, Luxembourg, Sweden, Switzerland, UK
Limits in radioactivity in food	All countries
Limits on imported foods	All countries (EEC)
Ban on grazing cattle outdoors	Austria, Bulgaria, Denmark, Federal Republic of Germany, Greece, Netherlands

Based on a report for the CEC by CEPN (Centre détude sur l'évaluation de la protection dans le domaine nucléaire) and a study by the US Department of Energy (Lombard, 1987).

building up in the milk, and data being gathered by local authorities had not yet been centralized and analyzed.

The top priorities for the CEC were the protection of health of its population and the reestablishment of the Common Market in foodstuffs, which had been interrupted by the various internal frontier measures. If previously agreed upon DRLs had been available for foods, this problem would have been easily resolved, even in the absence of mandatory legislation.

The free circulation of goods is one of the principles enshrined in the EC Treaty. Many restrictions on free circulation of foods arise from differences in national measures taken to protect health. For nearly two decades, the CEC has been engaged in the difficult task of removing these restrictions. National measures that were not fully justified by essential requirements such as health were attacked using Article 30 of the EC Treaty, as in the case of the German Beer Law. Article 100 of the EC Treaty was used to harmonize essential requirements, such as food additive limits, by means of binding EC Council directives (EC, 1973). Directives taken under Article 100 had to pass through the European Parliament and the Economic and Social Committee, frequently requiring four to five years before being adopted unanimously by the Council (now by qualified majority under article 100A of the Single European Act). Even if accelerated procedures had been used, the process could have taken months, and it was clearly not possible to pursue this route if the problems created by Chernobyl were to be resolved immediately.

The first problem to be dealt with was that of I-131. Many Member States had already fixed limits for the level of I-131 in foods, and these varied widely. In view of the national measures already taken, rapid agreement on mandatory limits for this radionuclide was improbable. Therefore, on May 6, the Commission issued a recommendation proposing that EC Member States should not obstruct the free circulation of food meeting the levels of contamination based on the most restrictive national levels being applied within the EC. These were 500 Bq/l for I-131 in milk, 500 Bq/kg for dairy products, and 350 Bq/kg for leafy vegetables. These levels were to be reduced by a factor of two after each of two successive 10-day intervals. The relation of the cesium radioisotopes to I-131 in the fallout was such that the I-131 limits would effectively control cesium in the immediate post-accident period.

Essential features of the recommendation were that Member States should mutually recognize official controls made by other Member States, should not apply stricter limits to products imported from other Member States than those they applied to their own produce, and should inform the CEC of action taken (EC, 1986a).

Since products coming into the Community and entering into free circulation cannot be obstructed at national frontiers inside the Community, the integrity of the Common Market could only be preserved if there were EC measures on food contamination for imports from non-EC countries. The total absence of information on the accident and the scale of the release weighed heavily in national decisions that had already been taken on imports from the USSR and Eastern Europe. Immediate notification of the accident by the USSR, together with estimates of the release and outlines of a possible course of events, would have greatly facilitated crisis management in Europe.

It appeared that the only measure likely to gain approval would be a temporary total ban on imports of food from the USSR and Eastern Europe, and a proposal to this effect was made by the CEC to the Council on May 6. The ban was to last until May 31, by which time common measures on the radioactivity of foodstuffs imported into the EC were to be implemented. Difficulties were encountered in the Council because some Member States considered that the I-131 levels set by the Federal Republic of Germany for leafy vegetables were too restrictive. They called on the CEC to attempt to agree to higher levels, although all other Member States could agree it was impossible to obtain unanimity.

The Council finally adopted the temporary ban on May 12 (EC, 1986c). Secondary legislation in the veterinary field permitted the CEC to act more rapidly on meat. After consulting the Standing Veterinary Committee, the Commission banned the import of bovine animals, swine, and fresh meat from the same East European countries on May 7 (EC, 1986b).

The continuous flow of information through the rapid alert system, which permitted an evolving picture of food contamination throughout the Community to be drawn up, was one of the most important factors that contributed to the building of confidence between authorities in EC Member States.

The CEC called a meeting of representatives of the countries of the European Free Trade Association (EFTA, comprising Austria, Finland, Iceland, Norway, Sweden, and Switzerland) within the framework of the EC/EFTA agreements. An informal understanding was arrived at; all parties agreed for the meantime not to apply stricter rules to imports from each other than they applied to products from their own territories. There was also a regular flow of information between the CEC and EFTA countries on levels of contamination. Consultations were held with Yugoslavia under the EC/Yugoslavia agreement, and informal talks with other Eastern European countries.

By the second week in May, a clear position on contamination levels of food was emerging, and it was evident that Cs-134 and Cs-137 would be the predominant radionuclides determining the radiation dose to the population through the food supply. After several consultations with EC food and radiation safety experts, the CEC proposed to the Council that the import ban should be replaced by a system whereby food imports from all non-EC countries would be subjected to radioactivity limits based on the sum of Cs-134 and Cs-137 (total cesium). On May 30, the Council adopted Regulation 1707/86, which set limit values for imported foods as shown in *Table 4.3* (EC, 1986d). These limits are somewhat lower than those recommended to the Commission on a scientific basis (1,000 Bq/kg) since the Council took into account other influences such as limits adopted by some of the EC's trading partners. The scientific limits were based on the International Commission on Radiological Protection (ICRP) recommendation. This recommendation used a more simplified approach to food intake than was used in the later calculations of DRLs described at the beginning of this chapter.

It is important to note that although lower levels were chosen for milk and baby foods, the concentration clause enabled dried products to have radioactivity levels of a factor of 4 to 10 above this limit, depending on the extent to which they were to be diluted for consumption. The exact concentration factors and the methods of analysis were left to the discretion of the control authorities because it was not possible to define a unique dilution coefficient, but this did not provoke any serious difficulties in control.

Table 4.3. Permissible levels of radioactivity in foods imported into the EC.

Products	Cs-134 and Cs-137 (Bq/kg)
Milk: liquid, dried, concentrated, condensed, and infant formulas	370[a]
All other foods	600

[a] The level applicable to concentrated products shall be calculated on the basis of the reconstituted product ready for consumption.

Two other points are worth noting. At the moment of adoption of Regulation 1707/86, the Member States declared that they would not apply stricter limits to trade between Member States than those required for import from non-EC countries, since it would be illogical to apply stricter limits to EC goods than to imported goods that were in free circulation. This declaration established common standards for intra-EC trade, thus avoiding the lengthy procedure of a directive referred to earlier. Although Member States were free to adopt whatever levels they wished for foodstuffs produced and consumed in their own territories, most adopted limits either identical or equivalent to those of 1707/86. Regulation 1707/86 was scheduled to expire on 30 September 1986, but was renewed twice: on 30 September 1986 and on 27 February 1987, finally expiring on 31 October 1987 (EC, 1986e and 1987a).

At each renewal there was intense discussion among the EC Member States on the appropriate limits to be applied. Some Member States wished to have new limits calculated on the basis of the DRLs that were concurrently being developed by the EURATOM Article 31 Committee. *Tables 4.1* and *4.3* illustrate that for total cesium the DRLs were higher than the limits in Regulation 1707/86 by a factor of eight, although the I-131 in dairy products was the same as that in the recommendation of May 6.

In making its proposal for a permanent regulation for radioactivity in foods in the event of a future nuclear accident, on 2 July 1987, the CEC took into account not only the DRLs proposed by the Article 31 Committee, but also the degree of public concern, the implications for Community trade, and the relationship to levels in force elsewhere in the world.

The Council failed to agree on this proposal by the expiry date of Regulation 1707/86 on October 31, but the EC Member States continued to apply the limits in 1707/86 until the permanent regulation was adopted on 22 December 1987 (EC, 1987c). This permanent regulation is, however, intended to apply to future accidents, and the limits of 1707/87 were embodied in a new regulation to apply to Chernobyl adopted also on 22 December 1987 for a period of two years (EC, 1987b). Thus the limits decided on 30 May 1986 were to run until 21 December 1989.

In the two years that followed Chernobyl, 119 consignments of food were refused entry into the EC. Up to the end of 1986, these were mostly live animals, the control of which is very difficult, particularly in the case where most consignments were made up of animals from various locations. At a later stage, tea, herbs, and hazelnuts predominated. The EC regulation provided for the possibility to allow exporting countries to designate laboratories to issue radioactivity certificates to remove the need for systematic control at the EC frontier, and a number of countries availed themselves of this facility.

4.3 Reactions of Other European Countries

Some of the countermeasures taken by several non-EC countries have been summarized in *Table 4.2.* It is not possible in this brief account to give a full chronology of the development of permitted radioactivity limits in food for all non-EC European countries. Several countries are therefore dealt with in summary form, and the events in Austria are described more extensively as a specific example of measures taken in one nation where many decisions were made.

In Finland, tolerance levels in foodstuffs were calculated from the ICRP recommendation, the major foods being defined as milk, beef, pork, and grain. Action levels were fixed at the following:

- Milk: I-131, 2,000 Bq/kg; Cs-137, 1,000 Bq/kg.
- Beef and Pork: Cs-137, 1,000 Bq/kg.

The Swedish National Food Administration also adopted the ICRP recommendation. The following guidelines for food contamination were decided on 16 May 1986 for all foods on sale in Sweden: I-131, 2,000 Bq/kg; Cs-137, 300 Bq/kg; and Cs-134 and Cs-137, 450–480 Bq/kg.

At the outset, Switzerland did not set tolerance limits for Cs-137, but the ICRP recommendation was used by the administration as a surveillance criterion. From November 1987, the EC limits set out in 1707/86 were applied.

Airborne radioactivity levels in Austria began to rise in the afternoon of April 29, but significant fallout only occurred on April 30, when it rained. The Health and Environment Ministry immediately called an expert group together and issued warnings against the consumption of fresh vegetables, the pasturing of cattle, contact with soil and vegetation, and the use of children's sandpits; it also advised frequent hand washing and cleaning of footwear. An extensive sampling campaign of dairy products at 214 points was carried out. The radioactivity increased on May 1, and further warnings were issued including advice to keep children indoors and to avoid contact with pets. Further advice of this kind was given, and later assurances were given that normal behavior could be resumed. However, even as late as July 8, the Minister, while assuring that "there was no danger in going out-of-doors," also said "however, direct contact with the ground such as sunbathing should be avoided."

Agricultural measures included:

May 3: A ban on the import of milk products and fresh vegetables from Eastern Europe, later extended to Albania, Greece, Italy, Turkey, and Yugoslavia.

May 4: A ban on the sale of fresh field-produced leafy vegetables (lifted on May 20).

May 7: A ban on the feeding of dairy and later store cattle and poultry with fresh fodder, pasture, or whey. (This ban was ignored by farmers owing to the shortage of alternative animal feeds.)

May 16: A delay of the hunting season for game (till June 15) and a ban on imports of game meats (lifted on June 11).

The actions on radioactivity limits in foods can be best followed when set out chronologically, *Table 4.4*. Since limits in Austria were defined in nanocuries (1 nanocurie = 37 Bq), numbers have been rounded to the nearest becquerel. In some cases, the limits are given only for Cs-137. To compare the effect of such a limit with one on Cs-134 and Cs-137, the limit should be multiplied by 1.6 since Cs-137 was about 60% of total cesium in the fallout.

4.4 Measures Taken by Non-European Countries

Europe is an important exporter of food; EC exports for foods amount to 20.10^9 ECU (US $\$23.10^9$) or about 20.10^6 tons. The CEC with the help of the European Association of Infant Food Manufacturers (IDACE) has compiled a list of measures applied by 77 non-EC countries; of these countries, 54 require a radiation certificate for each consignment on export. Countries have many specified limits, but often these are so complex that it is not possible to set them out in detail. *Table 4.5* shows in simplified form the requirements for two main groups of foods, dairy products and other foods, for countries where the limits are known. European countries are included in the table for comparison. Where a figure was specified for both milk and dairy products (dried milk, cheese, yogurt, etc.), the figure for these products has been used rather than that for milk only. Some countries have "concentration clauses" for dried milk similar to those in force in the EC, some exclude this type of calculation, and others do not state whether such a clause is operative or not. Some countries have specified Cs-134 and Cs-137 separately, and in this case the levels have assumed to be additive for the purposes of deciding into which group they fall.

Group 1: Twenty-five countries with limits equal or close to the EC limits.

Group 2: Eight countries equal or close to US limits.

Group 3: Countries with fixed limits significantly below the USA, but above 100 Bq/kg.

Table 4.4. Chronology of radioactive limits set on food products in Austria.

Food product	Date	Radionuclide	Bq/kg	Notes
Milk, yogurt, and similar products	May 2	I-131	370	Recommended that only products below 185 should be sold.
	May 26	I-131	185	
	May 29	I-131	74	
	May 31	Cs-137	74	
	July 17			Limits set on milk from cows and later applied to sheep and goats, the sale of which had been forbidden since May 7.
Infant foods	May 23	Cs-137	11	
Cheese	May 31	Cs-134 and Cs-137	370	Including fresh cheese.
	June 6	Cs-134 and Cs-137	592	Except fresh cheese.
	June 9	Cs-137	185	Fresh cheese.
Fruit, vegetables, and their products	May 5–22			Banned (lifted on salad on May 22).
	May 23	I-131	185	
	June 5	I-131	74	
		Cs-137	111	
	June 26	Cs-137	370	When sold for manufacture.
	Sep. 18	Cs-137	592	For shelled nuts.
Meat	June 3	Cs-134 and Cs-137	185	
	June 4	Cs-134 and Cs-137	555	
	June 9	Cs-134 and Cs-137	592	
	July 15			Limits on game lifted.
Honey	June 9	Cs-134 and Cs-137	592	

Table 4.5. Summary of levels set by countries for imported foods.

	Dairy products			Other foods		
Country	Cs-134	Cs-137	Total Cs	Cs-134	Cs-137	Total Cs
Group 1						
Finland	–	–	1,000	–	–	1,000
EC 12	–	–	370	–	–	600
Abu Dhabi	–	–	370	–	–	600
Brazil	–	–	370	–	–	600
Cyprus	–	–	370	–	–	600
Egypt	–	–	370	–	–	600
Hungary	–	–	370	–	–	600
Israel	–	–	370	–	–	600
Switzerland	–	–	370	–	–	600
USSR	–	–	370	–	–	600
Sweden	–	–	300	–	–	300–1,500
Belize	370	370	–	370	370	–
Algeria	267	302	–	267	302	–
Argentina	–	–	500	–	–	–
Group 2						
USA	–	–	370	–	–	370
Japan	–	–	370	–	–	370
Nigeria	–	–	370	–	–	370
Taiwan	–	–	277	–	–	–
Venezuela	–	–	250	–	–	300
Tunisia	–	–	100	–	–	500
Canada	100	100	–	300	300	–
Jordan	–	–	250	–	150–250	–
Group 3						
Malaysia	120	60	–	216	108	–
Indonesia	–	150	–	–	150–300	–
Syria	–	–	150	–	–	150
China	–	–	148	–	148	–
Group 4						
Australia	–	–	100	–	–	100
Morocco	–	100	–	–	100	–
Bangladesh	–	–	95	–	–	50
Kuwait	–	–	90	–	–	–
Qatar	–	–	30	–	–	75
Saudi Arabia	–	–	30	–	–	70
Philippines	–	–	22–33	–	–	6–28
Thailand	–	–	21	–	–	7
Iran	–	–	10	–	–	10
Singapore	–	–	0	–	–	0

Group 4: Ten countries with limits at or below 100 Bq/kg; all are Middle East or Pacific basin countries.

The limits set by the EC on 30 May 1986 for dairy products were clearly influenced by the existing USFDA levels for cesium which had been decided on 15 May. The decision taken by the EC can be seen to have had a very important effect not only on its immediate European neighbors, who were equally affected by fallout, but also on its non-European trading partners.

Countries in Southeast Asia and Australasia set the lowest limits. In these regions, the fallout from Chernobyl was negligible, and crop contamination was scarcely above the pre-Chernobyl background from residual fallout of weapons testing of the 1960s. Governments had more freedom to set limits, which in many cases were well below the natural K-40 radioactivity in the foods concerned, since imports from Europe could easily be replaced by those from New Zealand and Australia or by processed products from Japan.

It is remarkable that most of the countries in this region acted several months after Chernobyl, as is shown on *Table 4.6.* Australia and New Zealand were the first to act in the region, and there was a domino effect culminating in the introduction of measures in Thailand in November, following a vigorous press reaction where one Thai newspaper depicted Europe as a tiger being milked of radioactive substance by a Thai peasant.

A few countries have been selected for a more detailed description of actions taken to illustrate the diversity of policies of governments.

On May 12, Canadian customs was instructed to control all shipments of fresh food produced in Europe and to destroy anything contaminated above natural levels. On May 15, the Canadian government fixed tolerance levels for I-131 in milk and produce, and a more comprehensive list of screening levels was adopted at the end of June:

- Milk: Cs-134, 50 Bq/l; Cs-137, 50 Bq/l; and I-131, 10 Bq/l.
- Dairy products: Cs-134, 100 Bq/l; Cs-137, 100 Bq/l; and I-131, 40 Bq/l.
- Other foods: Cs-134, 300 Bq/l; Cs-137, 300 Bq/l; and I-131, 70 Bq/l.

To December 1986, the Canadian authorities rejected only 12 consignments of imported European food out of 300 tested.

Japan introduced no specific measures on radioactivity in foods until six months after Chernobyl, even though the population was advised not to drink rainwater at the time the diluted cloud from Chernobyl, having traversed the whole of Asia, passed over Japan. On 31 October 1986, a Japanese expert committee recommended a limit of 370 Bq/kg on Cs-134 and Cs-137 in foodstuffs, which was put into force by customs authorities in November 1986. A sampling regime of 10% of import consignments was imposed. In February 1987, following the discovery of contaminated nuts from Turkey, the degree

Table 4.6. Dates of adoption of permitted radioactivity levels in foods by some non-European countries.

Year	Month	Country
1982		USA
1986	May	Canada, Saudi Arabia
	June	Israel, Australia, New Zealand
	July	Singapore
	August	Philippines
	September	Malaysia
	October	Japan, Jordan
	November	Thailand
1987	May	Mexico, Nepal

of inspection was extended to all consignments of nuts from Europe and later to all consignments of food and liquor from eight European countries, leading to customs clearance delays. In November 1987, the customs regulation was extended for another year. The Japanese authorities detained only 25 consignments of food from Europe up to February 1988, of which 10 consignments were of EC origin (mostly nuts and herbs).

In August 1986, the Philippines stated that, "in the aftermath of the Chernobyl accident, foodstuff imports were to be safe, and free from radioactive substances" and that "exporters should provide certificates to that effect with their goods." A week later on August 20, a very low tolerance level of 22 Bq/kg of total cesium was specified for milk. At the end of August and the beginning of September, a spate of newspaper articles reported the withdrawal of European foodstuffs from shops, and subsequently the following limits were set on Cs-134 and Cs-137:

- Liquid milk: 15 Bq/l.
- Milk powder (full cream/nonfat), whey powder, infant food anhydrous milk fat/butter fat, cream (raw), butter: 22 Bq/kg.
- Cheese: 33 Bq/kg.
- Vegetable products: 22 Bq/kg.
- Fruit products: 8 Bq/kg.
- Meat products: 6 Bq/kg.
- Cereal products: 6 Bq/kg.
- Fish/marine products: 28 Bq/kg.
- Cocoa powder, chocolate drink, candies, tonic drink, coffee: 22 Bq/kg.
- Dextrose, glucose, honey: 2 Bq/kg.

As mentioned above, US guidelines were originally established by the FDA in 1982, and from these maximum levels of radioactivity the so-called action levels for imported foods were calculated and published in the Federal Register of 25 June 1986 (USFDA, 1986b):

- Infant foods: I-131, 56 Bq/kg; Cs-134 and Cs-137, 370 Bq/kg.
- Other foods: I-131, 296 Bq/kg; Cs-134 and Cs-137, 370 Bq/kg.

These action levels applied to foods that are regulated by the FDA, but the US Department of Agriculture (USDA), through other legal instruments, was applying a limit of 2,800 Bq/kg of total cesium for meat. On 3 November 1986, six months after Chernobyl, the USDA reduced the limit for meat to 370 Bq/kg. The FDA informed the CEC soon after the calculations had been made on 16 May 1986 (USFDA, 1986a). During the period from the end of April 1986 to 8 December 1987, the US authorities detained only 15 consignments of food from Europe that exceeded the FDA levels (USFDA, 1987).

Middle East countries pursued an intermediate course. In many cases, limits were based on the advice of scientists, and the starting point was the 5 mSv ICRP recommendation, although the fixed levels differed markedly from country to country.

4.5 Effects on Trade and Agriculture

In the days and weeks immediately following Chernobyl, the various governmental warnings and decisions had direct but very localized effects on trade and agriculture, which it is possible to quantify. Bans on the sale of perishable goods, such as spinach in the Netherlands and in some German Länder and green vegetables in Italy, resulted in the loss of some perishable crops, as did the obstruction of lorries at the borders carrying similar commodities. The issuing of warnings also deflected public choice away from specific foods, but it is not possible to quantify the loss of perishable foodstuffs in this period. Once legal limits had been established in the EC, the majority of foodstuffs in trade was found to conform. Notable exceptions were game in alpine areas, sheep in the northern part of the United Kingdom, and herbs, mushrooms, and durum wheat in Greece.

The cesium contamination of sheep in the UK persisted into 1988, and was caused by a combination of the high local wet deposition in hilly areas, the grazing habits of the animals, and the behavior of cesium in the acid soil conditions found in these areas. To deal with this problem, the United Kingdom introduced a program of control and transhumance. The areas to be controlled were identified by an initial survey, and the sale of sheep for slaughter from the affected areas was forbidden – control being exercised by marking the sheep. Marked sheep could be sold for fattening on lowland pastures that were not contaminated, and payments were made to farmers to compensate them for the difference between the price achieved under the scheme and the market price for slaughter. As cesium levels decreased, the restricted areas were reduced on the basis of surveys carried out by the authorities. Considerable variations were encountered in measurements made on live animals, even when taken from a relatively small area, and the authorities used a statistical method of assessment. In the initial stages, reliable measurements could only be made on slaughtered animals but later a method of screening live animals was developed.

After the 1986 harvest had been checked, the Greek government reported that a very large quantity (about 60,000 tons) of durum wheat was above the 600 Bq/kg limit set by the EC for imports and applied by EC countries for intra-EC trade. Experiments showed, however, that the semolina produced by milling this wheat was well below the 600 Bq/kg level since the contamination was largely on the outside of the grain, which was removed in milling. Much of the Greek durum wheat, however, is sold in the unmilled state to Italian firms for processing into pasta and couscous. Italian law applied the 600 Bq/kg limit so that the wheat could not be imported in the unmilled state, thus reducing its value in trade. On two occasions, when the renewal of Regulation 1707/86 was under discussion, the Greek government attempted unsuccessfully to get a derogation for goods that were not ready for consumption. The problem was finally solved by making special arrangements for milling the wheat.

In addition to government measures, many companies or traders applied limits that were stricter than those set by law as deliberate policy, partly to avoid the negative publicity that could have arisen if brand-named products had been found to be contaminated above the levels, and partly to cover potential concentration effects in processing. One company that made products using milk as a raw material set a limit of 100 Bq/kg of cesium on raw milk. Since the concentration clause in the EC regulation applied only to products to be re-diluted before use, this was probably a prudent action because powdered milk, had it been made from 100 Bq/kg liquid, could have had as much as 1,000 Bq/kg. This powder is also used as a solid ingredient in some foodstuffs, such as chocolate or chocolate drink powders, which did not benefit from the dilution clause and could have consequently exceeded the 600 Bq/kg limit.

Some breweries set limits for malt of 50 Bq/kg or even as low as 10 Bq/kg. These were not justifiable on processing grounds since the malt undergoes considerable dilution in the manufacture of beer, and, although distilling malt ferments to produce spirits is a concentration process, the cesium remains in the distillation residues.

On both a national and an international scale, traders used the origin of foodstuffs in areas known to be less contaminated as a selling point. In one EC Member State, a large chain of supermarkets, while making no special claims for low contamination, labeled all vegetables and fruits with their country of production where this was known by the public to be only slightly contaminated. On the international scale, the low contamination of dairy products from countries in the Southern Hemisphere was emphasized by traders from that area.

4.6 Costs of Chernobyl

The value of crops that perished, were destroyed, or were refused in trade in "non-state-trading countries" after Chernobyl was an extremely small proportion of the total annual value of the food supply. Nevertheless, the concentration of the problem in specific areas bore very heavily on the farmers or traders directly involved in specific crops or transactions. Although purchasing habits of consumers were temporarily perturbed, they soon returned to normal so that the producers of nonperishable products were temporarily affected in terms of volume but probably had to lower prices to reintroduce products. The cost of the compensation scheme for sheep to public funds in the UK up to the end of 1988 was about US $8.5 million, but the significant losses for farmers and traders caused by public reaction cannot be quantified.

The Greek durum wheat that exceeded the limits was mixed with about double the quantity of uncontaminated wheat from subsequent harvests. From trading sources it is alleged that the price of this blended wheat was about US $50 for each ton below the normal price, thus the net loss on the sale would be US $100 million.

The complexity of economic factors touching international trade makes it impossible to isolate with certainty the consequences of radioactivity from economic factors. This is demonstrated by the statistics of exports of milk and concentrated milk from the EC to non-EC countries that are shown in *Table 4.7.*

As a whole, exports for 1986 were 13% below the average for the two preceding years and the following year. An examination of monthly trade figures, however, shows that in the four months preceding Chernobyl exports were 22% below normal, 17% below normal in the following four months, and back to normal in the last four months of 1986. The low annual exports for 1986 were almost wholly caused by pre-Chernobyl economic factors.

The relatively temporary effect of Chernobyl is shown by statistics of exports to Thailand where severe measures were introduced in November 1981. A fall in imports to less than 20% of the monthly average in December 1986 was more than recovered within three months.

A number of individual incidents resulted in heavy costs for traders from European countries. One case that illustrates the difficulties, for both traders

Table 4.7. Export of milk, cream, and preserved, concentrated, and sugared milk (in metric tons) from the EC to non-EC countries.

Destination	1984	1985	1986	1987
USA	1,801	3,885	1,904	2,226
Canada	1,525	1,804	1,698	2,828
Mexico	33,391	36,827	38,806	61,513
Brazil	3,411	1,234	71,220	1,435
Venezuela	84,596	49,721	14,785	44,804
Thailand	6,963	6,863	8,974	26,790
Malaysia	11,257	9,771	10,027	12,598
Singapore	14,432	12,790	7,473	5,931
Philippines	13,488	16,849	27,345	47,355
Japan	11,801	15,054	12,311	29,967
Nepal	508	486	437	1,002
Burma	6,317	6,937	5,077	3,635
Kuwait	18,592	19,021	20,113	21,158
Saudi Arabia	120,245	94,104	114,118	109,815
Israel	2,387	7,368	5,594	5,312
Algeria	151,519	194,147	131,593	156,192
Ghana	2,877	2,230	1,906	1,495
Jordan	11,560	13,409	11,968	13,340
All non-EC	1,383,889	1,395,957	1,206,417	1,394,262

and authorities, of dealing with such problems was the export of 6,000 tons of beef from Ireland and Denmark to Venezuela in May 1987. This consignment was frozen beef produced after Chernobyl. It was checked by reputable laboratories in Ireland and certified as being below acceptable limits. On arrival in Venezuela, one sample was found to show a relatively high level of radioactivity, more than 600 Bq/kg of cesium. After one year of negotiation, the whole consignment was replaced, the original meat being reexported. While the consignment was in transit in a port in the Netherlands, the veterinarian authorities sampled and analyzed more than 600 packs of the meat, only one of which was found to have a radioactivity level of over 600 Bq/kg. Half of the packages were found to be at or below the level of detection (40 Bq/kg), despite the fact that sampling was concentrated on packages coming from the plant that had given the high contamination level. The costs of this operation for public authorities and for the traders involved must have been several million dollars.

The costs of analyses for export certificates are relatively high, about US \$100 per sample, and total costs must be of the order of US \$4 million per year for European exports of dairy products alone and possibly US \$40–50.10^6 for all foods. Although all crops in 1988 were below all but the very lowest limits set by authorities, governments continued unnecessarily to require certificates of radioactivity on exported products. The cost of discounts, given to reestablish commercial markets, is unquantifiable. There is some evidence that they were given since the unit value of exports was lower in 1986. If they were 5%, then the cost could be of the order of US $1 billion. Added to these industrial costs are the extensive costs incurred by public authorities to control and monitor programs that were instituted at the time of Chernobyl, although in many cases these were reduced to a standby level by the end of 1988. Overall costs to EC authorities and private operators must amount to several billion dollars.

4.7 Lessons to be Learned

Of necessity this has been a very summary account of action following the Chernobyl accident, but it highlights the need for a number of actions which would greatly reduce unnecessary cost and public alarm in any future incident.

Early warning and assessment. The existence of an early warning system would have enabled control and surveillance systems to have been set in motion as soon as the accident occurred, giving several days preparation in some cases. The IAEA convention of 1986 is an important step forward in this respect.

National and international communications. Control and reporting networks should be set up and should be operational so that an ongoing picture of the situation is available in any future accident.

Prefixed radioactivity limits for foodstuffs. DRLs must be available at a national and international level, and ideally both should be identical. The EC has declared its intention to work toward this end (EC, 1987d), and a proposal is being prepared by the WHO/FAO Codex Alimentarius (Codex, 1988).

Agreed methods of sampling, statistical analysis, and dispute resolution. Legal certainty requires fixed limits, but the statistical spread of contamination, as demonstrated by Chernobyl, requires the development of agreed methods of sampling and, in particular, statistical analysis of results.

Coordinated recommendations for other countermeasures. Much public alarm was created by well-meaning but exaggerated advice given by governments, the media, and experts, both official and self-styled. A code of recommended countermeasures and advice would help greatly to reduce confusion.

Measures for local application. There is little possibility that DRLs on an international scale will be agreed upon at much higher levels than those currently in discussion in Codex and adopted by the EC for future use (ca. 1,000 Bq/kg total cesium), although post-Chernobyl experience has shown that dose levels in an incident would be much lower than 5 mSv even if DRLs were attained. The application of such restrictive limits in the area immediately around a reactor site following an accident could cause severe difficulties with food supply. For these circumstances, a planned system of interactive incident control in which dose rate is continuously assessed is necessary.

Simple radioactivity limits. Although scientific limits could be fixed separately for each radionuclide, there would be no real gain in protection, and the complexity of differentiated limits in practical control argues strongly for few simple limits.

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Chapter 5

The International Response: Prospects for a Nuclear Safety Regime

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In April 1986, the Chernobyl nuclear reactor breached containment and released more than 100 million curies of radioactivity into the environment. The release from this *worst case* accident, which has been compared to several dozen Hiroshima bombs (Hohenemser and Renn, 1988), conformed little, if at all, to accepted nuclear accident scenarios. To everybody's relief, there were far fewer immediate fatalities in the Ukraine than would have been anticipated. Actual deaths, however, instead became anonymous statistical deaths. The radionuclide contamination reached most of the Northern Hemisphere, and expected future cancer fatalities may be in the thousands.[1]

This global radionuclide contamination was a surprise to the nuclear community, and triggered a novel international political recognition of a shared, global responsibility for the safety of nuclear installations. Chernobyl changed the very *definition* of nuclear risk. What was seen primarily as a local or national problem has now become a transboundary problem with regional, and even global, dimensions. Nuclear risk has thus joined the rapidly expanding family of global environmental issues, such as ozone depletion, climate warming, acid rain, and tropical rain forest destruction. The abrupt and dramatic emergence of these transboundary issues is an important element in shaping institutional responses.

As a transboundary problem, nuclear risk is unique in two respects. The Chernobyl release was the first to place the *risk* of a technological accident on the international agenda, although the Rhine River disaster following shortly thereafter tragically repeated the message that technological accidents can have far-reaching effects (Linnerooth, 1988). Second, and more important, the nuclear issue is one of the few global problems for which long-standing international organizations exist with formal responsibilities for its management.[2] The most important such institution is the International Atomic Energy Agency (IAEA), which is a functional body concerned with promoting the peaceful uses of nuclear technologies. Other relevant UN organizations, although directly concerned to a far lesser extent with nuclear problems, are the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the International Labor Organization (ILO). Influential bodies outside the UN include institutions of the European Communities (EC) and the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD).

In the aftermath of Chernobyl, demands were made for an international nuclear safety regime that would ensure comparability of standards, effective transfer of data between national industries and authorities, and genuine improvements in safety and emergency response. The IAEA was the only network already in existence with nuclear expertise, a fund of relevant data, and the necessary global reach. It was therefore natural to see it as leading attempts at international safety harmonization put in train by the 1979 Three Mile Island accident in the USA. However, the stakes had been raised by the Chernobyl accident, so much so as to pose a new set of aims and challenges, which could even require intervention in national regulatory processes.

Substantial reorientation is required if the international community is to play anything more than a clearinghouse role. Therefore, it is relevant to ask, several years after Chernobyl, what has been achieved by the international community and what are the prospects? Can existing international organizations effectively contribute to the control of the risks of further global pollution from more than 400 civilian nuclear power plants in 26 countries and associated shipments of radionuclides numbering between 18 and 39 million packages per year? Or will the gap between the apparent achievements of international environmental diplomacy and the actual environmental results, as Carroll (1988) warns, also materialize for nuclear power?

This chapter addresses these questions by examining the international organizations responsible for nuclear safety in Europe. The chapter begins not with the Chernobyl accident, but with the 1979 Three Mile Island (TMI) accident in the USA, since the TMI accident (in contrast to the Windscale accident in the UK) focused international attention on nuclear accident preparedness. Section 5.2 shows how international organizations, already acutely aware of the possibility of a severe nuclear accident, responded to Chernobyl. Section 5.3 addresses the question whether and, if so, what kind of an effective international regime for nuclear safety might evolve.

5.1 International Organizations and Nuclear Safety after TMI

The euphoria over nuclear technology as an energy source in the early 1950s was followed by intense public debate over its risks. This debate, along with spiraling capital costs, has seriously damaged earlier faith in the advancement of nuclear technology.[3] The international response has been varied, but generally international organizations have only slowly turned their attention to preventing major nuclear accidents or reducing their consequences with emergency response measures. Early efforts in the area of nuclear safety focused, rather, on two other important problems: protecting workers and the public directly at risk of exposure to ionizing radiation, e.g., medical applications and occupational safety, and ensuring that nuclear materials from the civilian uses of nuclear power were not diverted for military purposes. The International Commission on Radiological Protection (ICRP) was accepted as the international authority on the former, whereas the IAEA was responsible for the latter under the Non-Proliferation Treaty (NPT).

The safety of nuclear power plants, especially those in developing countries, slowly emerged as an issue on the international agenda. Accident mitigation, on the other hand, was considered to be the responsibility of national governments and little serious regulatory attention was given to emergency planning. In no small measure, this was due to the widespread assumption that a serious reactor accident simply would not happen.[4]

The TMI accident in 1979 drastically reversed the nuclear community's belief that major accidents were not the central problem of nuclear energy. TMI was a surprise and a shock to the industry. An accident that developed slowly and in a confusing manner had not been anticipated by accident management plans, which were geared only to well-understood accidents (Lathrop, 1981). While TMI reportedly did not shake industry's faith in the probabilities, it did change the perception of the consequences. Senior industry representatives admitted that a very serious reactor accident, one that caused many people to die, would probably shut down the industry (Weinberg, 1985, p. 76). As the IAEA Director General has often warned, "an accident anywhere may affect attitudes to nuclear power everywhere" (Blix, 1986).

An important outcome of the TMI accident and the subsequent post-mortem was a reorientation in the overall risk assessment programs of both the US government and industry (see Kasperson and Gray, 1981). First, the focus in the WASH-1400 report (US NRC, 1975) on catastrophic but very low-probability events (big pipe breaks and large, rapid transients) was shifted toward higher-probability/lower-consequence-initiating events. Second, significantly more attention was given to human error as an ingredient in reactor accidents. WASH-1400 was inadequate in its attention to this issue, and a number of analyses, some even before TMI, showed that human failure might be responsible for a large proportion of all reactor risks [see, e.g., Deutsche Gesellschaft für Reaktorsicherheit (German Reactor Study), 1979]. Despite these revelations, the NRC continued to give insufficient attention to research on human factors and operator training, and budged very little from its traditional emphasis on equipment problems (US GAO, 1980).

The third reorientation concerned accident mitigation, especially emergency planning and siting, areas that had been given little priority by industry and the NRC. The TMI accident clearly demonstrated that none of the responsible parties was prepared for a major nuclear accident. The Presidential Inquiry Commission (Kemeny Commission) was blunt in its appraisal:

> The response to the emergency was dominated by an atmosphere of almost total confusion. There was lack of communication at all levels. Many key recommendations were made by individuals who were not in possession of accurate information, and those who managed the accident were slow to realize the significance and implications of the events that had taken place. [US President's Report, 1979, p. 17]

The confusion in the USA, to which many countries looked as a leader in nuclear technology, was witnessed on televisions all over the world. The resulting international concern spurred a reaction from international institutions. The relevant international bodies and their responses to Three Mile Island, which set the stage for the Chernobyl accident to follow seven years later, are described below.

5.1.1 The International Atomic Energy Agency (IAEA)

Proposing the ambitious Atoms for Peace Program in 1953, US President Eisenhower called for the creation of the International Atomic Energy Agency. The IAEA was established in 1957 as an autonomous intergovernmental organization, although it is administratively a member of the United Nations. It has 113 Member States. The main objectives of the IAEA are to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world," and to "ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose." The Safeguards Program under the NPT is the Agency's main functional activity. The IAEA does not have authority to control the safety of nuclear installations or to formulate internationally binding safety standards. Its nuclear safety role is, thus, principally advisory. Early IAEA efforts in the safety field concentrated on occupational radiation protection for users of radioisotopes in medicine, industry, and agriculture.[5] In the Agency's second decade, when nuclear power became more widespread, the safety of nuclear power became more prominent on its agenda. In 1977, Rosen from the IAEA warned that developing nations might be buying and installing nuclear power plants that were less safe than those operating in supplier nations (see Ferrara, 1978). The Nuclear Safety Standard (NUSS) Program was started in 1974, and in the course of 11 years an internationally agreed upon set of codes of practice and safety guides for nuclear power plants was developed. These guides generally reflect established safety rules in the nuclear supplier countries.

The TMI accident did not signal a fundamental change in the Agency's position on nuclear safety, but it did result in a significant expansion of its safety activities. In 1982, the IAEA set up the Operational Safety Review Team (OSART) Program under which IAEA and outside experts make three-week reviews of safety practices at the request of Member Countries. A complementary activity is the Incident Reporting System (IRS) for which the IAEA in cooperation with the Nuclear Energy Agency of the OECD receives and disseminates information on safety-significant events occurring at nuclear facilities in participating states.

Even before the TMI accident, the IAEA had turned its attention to accident response. The accident in the USA, however, expedited these efforts. Safety Series publications following TMI cover topics on planning for off-site response to radiation accidents in nuclear facilities (IAEA, 1981), preparedness of public authorities (IAEA, 1982b), and preparedness of operating organizations or licensees (IAEA, 1982c). Along with other international bodies, the IAEA recognized the need to establish guidelines for national authorities to take action to protect the public from accidental radiation releases. Such actions are termed "interventions," and, following ICRP recommendations (ICRP, 1984), the IAEA supplemented its Basic Safety Standards (IAEA, 1982a) to address not only "design-base" releases but also severe nuclear accidents. In 1985, the Agency published guidelines on the principles for establishing intervention levels for the protection of the public in the event of a nuclear accident or radiological emergency (IAEA, 1985a). The relevant countermeasures included sheltering, evacuation, relocation, control of foodstuffs and water, and the use of stored animal feed. The Agency also began work on a supporting document giving more specific guidance on the setting of "derived" intervention levels (DIL) for foodstuffs and environmental materials. This document was in preparation at the time of the Chernobyl accident (IAEA, 1986a).

These guidelines were based almost entirely on recommendations made one year earlier by the International Commission on Radiological Protection (ICRP, 1984), which set out basic principles for planning interventions for serious nonstochastic effects and risks from stochastic effects.[6] The ICRP recommendations can be interpreted such that high risks to individuals should be avoided if at all possible (and, implicitly, regardless of expense), but low risks spread over a population should be avoided only if the costs are justified by the benefits. For each possible countermeasure, e.g., sheltering or evacuation, a lower level of dose is reported below which introduction of the countermeasure is not warranted and an upper level of dose is reported for which its implementation should be attempted.

To some extent, IAEA's post-TMI publications on emergency response anticipated a Chernobyl-type accident. While no discussion of the length or duration of radioactive plumes can be found, the possibility of wide-scale, transboundary consequences was not ruled out. In addition, the IAEA emphasized that the real situation would differ from the "reference accident" and that meteorological conditions would play an important role (IAEA, 1985a, p. 7). Severe uncertainties were also correctly foreseen (IAEA, 1985a, p. 12): "The data obtained from the plant and from the environment during a release may be incomplete, incorrect or wrongly interpreted."

Issues of information transfer and transboundary radioactive contamination would only become salient after the Chernobyl accident, yet the problem was anticipated one year earlier in an information circular describing guidelines for reporting and for integrated planning (IAEA, 1985b). The Agency had hoped to negotiate a convention on the early reporting of nuclear accidents and much preparatory work was undertaken. This convention, however, would have to await the Chernobyl accident with its more serious and widespread consequences.

5.1.2 The World Health Organization (WHO)

The World Health Organization, founded in 1948 as a specialized agency of the United Nations, has more than 150 Member Countries and aspires to the goal of "health for all by year 2000." With a budget for nuclear safety only a small fraction of that of the IAEA, the WHO has concentrated on protecting workers and the public from radiation. Its early work assisted Member States in understanding the public health implications from the widespread use of radioisotopes (WHO, 1957). As early as 1965, the WHO became concerned with the possibility of nuclear power accidents and published general guidelines for emergency health actions (WHO, 1965). Shortly before the TMI accident, the WHO Regional Office for Europe published a document describing the health implications of nuclear power production (WHO, 1977).

The TMI accident prompted the WHO to address specifically accidents at nuclear power plants. Like the IAEA report, the resulting document (WHO, 1984) adopted the recommendations made by ICRP. Recommendations are made on emergency plans, setting intervention levels (although the WHO's recommendations are less quantitative than that of the ICRP and IAEA), early communication to the public, and dealing with the anxiety and psychological effects on the population.

5.1.3 The European Communities (EC)

Unlike the UN, which is constitutionally limited to making recommendations to its Member States, the European Communities (EC) can issue directives that are binding on the European membership. In the area of nuclear policy, the EC bases its actions on the 1957 European Atomic Energy Treaty (EURATOM) with the purpose to "contribute to the raising of the standard of living in Member States by creating the conditions necessary for the speedy establishment and growth of nuclear industries" (Article One). Described as one of the least successful endeavors of the EC (Kohl, 1983; Goldschmidt, 1982),[7] EURATOM nonetheless enabled the EC to respond to the TMI accident by providing radiological protection criteria for controlling doses to the public from an accidental radiological release (CEC, 1982). The reference levels provided in this guidance preceded that of the ICRP (1984), the WHO (1984), and the IAEA (1985a). The guidance is similar, however.

The EC was less successful in contributing more than general guidelines to require explicit planning for transboundary contamination. In a Commission resolution submitted to the EC Council of Ministers concerning emergency planning and contamination of rivers and seas [Document COM (83) 472 final, 22 July 1983], the Commission identified the work it would undertake with respect to transboundary planning in the event of a nuclear accident. This resolution was not adopted on the grounds that it would be duplicating work done by the Member States. The Commission criticized this "negative standpoint" of the Council "which again underlines the independent attitude taken by Member States" (European Study Service, 1987).

5.1.4 Conclusion

In sum, the TMI accident signaled a rethinking of the risks of nuclear power on the part of the international community. While TMI had no serious physical consequences outside the plant, let alone in other countries, it presented the real possibility that a serious accident could occur despite the reassuring probabilities. Furthermore, it was recognized that an accident anywhere in the world could have dire consequences for the whole industry. After TMI, the international community therefore acted to improve nuclear power plant safety and to provide a more consistent approach to emergency response. This resulted in the international recommendations on criteria for the protection of the public in the event of a nuclear accident that have been described in this section. According to a recent NEA report, these recommendations "constituted a reasonably well developed international basis for emergency response" (NEA, 1987a, p. 45). With international recommendations in place, on the face of it a nuclear accident to follow TMI was anticipated. However, general recommendations were not the same as practical preparedness for a major accident.

5.2 International Response to the Chernobyl Accident

What went wrong? Despite elaborate post-TMI recommendations, and with the relative luxury of time to analyze and make decisions, the European response to the Chernobyl accident can only be described as chaotic. As the radioactive plume spread over most of Europe, the national authorities and the media were ill-prepared to define the risks and communicate them effectively to the public. Accusations of lack of information, contradictions, and misinformation were more the rule than the exception during the episode. Immediately after the accident, it became apparent that the formal arrangements for dealing with transboundary radionuclide pollution were inadequate.

In such emergencies information is invariably inadequate, and Chernobyl was no exception. Even the existing information about the developing situation at the reactor was not fully communicated to higher officials in the Soviet Union. Had there been full information, locally or centrally, no obligations existed for the countries involved to share this information with neighboring countries. In addition, the measures taken to protect the public differed widely among countries affected and even between states within countries. The response of the Benelux countries, which because of their proximity to each other suffered similar consequences, illustrates this. With regard to milk, for example, the Dutch government set a contamination maximum of 500 Bq/l, and 175,000 liters were confiscated. The Belgian government said milk was safe for consumption, but caution should be exercised in giving it to children. The Luxembourg government claimed milk to be perfectly safe for both adults and children (BEUC, 1986). In the Federal Republic of Germany, as another example, the mass of conflicting measures and advice between states and the federal government led many to near panic.

> A poll showed that 50% thought that the government had tried to hide the consequences to public health. Hotlines were inundated with calls and the

> country's entire stock of iodine tablets was sold out by 30 April.... By 6 May, no more Geiger counters could be bought anywhere in Germany. A few people left the country, the "Greens" in Munich suggested evacuating small children to Portugal, and some pregnant women even had abortions for the fear of the effect on their children. The population took to the streets in vast numbers to protest against nuclear power. [BEUC, 1986, p. 15]

Some countries, e.g., Finland and the Netherlands, even called for a freeze on their nuclear power programs.[8] Austria decided definitively against its moth-balled plant.

How can these disparate national responses be explained in light of the prodigious post-TMI planning efforts on the part of the international community? One obvious explanation lies in the inevitable gap between recommendations at an international level and their implementation by national or even local authorities. To illustrate this "implementation gap" more fully, the discussion will return again to the post-TMI preparations.

5.2.1 TMI revisited

Emergency planning following TMI did not change appreciably. At a post-TMI IIASA workshop, it was suggested that those presenting their national emergency plans would have given much the same presentation before the accident. Harold Collins of the US NRC replied:

> [That] is quite right ... because several of us, representing twenty countries, think that we have identified quite well what ought to go into emergency plans after more than four years of work on the question. This work was organized by the International Atomic Energy Agency. Because of the Three Mile Island accident, people think we should now go back and reinvent the wheel. [Lathrop, 1981, p. 28]

Given that there is an inevitable surprise element of the next accident, "reinventing the wheel" is always a problem. Still, it is noteworthy that the participants at the IIASA meeting did not recognize or deal with the possibility of transboundary contamination.

The IIASA participants also would not have anticipated the chaotic response to Chernobyl's radionuclide contamination. Uncertainty and confusion characterized the TMI response, but this kind of confusion was not anticipated for the later stages of a real release: "On a longer time scale other countermeasures may be taken, such as control of possibly contaminated food products, but these steps typically do not involve decision making under time pressure and uncertainty" (Lathrop, 1981, p. 6). Chernobyl, of course, proved the accident managers attending the IIASA workshop to be wrong.

In contrast to national emergency planners, international organizations, to some limited extent, did anticipate an accident with transboundary contamination. The concern, however, was only for power plants situated close to borders, arising from the controversy and anger created in the Federal Republic of Germany by the French policy of siting pressurized water reactors (PWRs) at the Rhine frontier. The resulting recommendations (IAEA, 1981; WHO, 1981) at the time of the Chernobyl accident were thus incomplete and partly irrelevant. These recommendations suggested that accident response should proceed in three stages corresponding to the early, intermediate, and recovery phases of the accident. After Chernobyl, many European countries found themselves in the "intermediate phase" without having been informed of the "early phase," and without any anticipation that they could have been so affected by a distant accident. This intermediate phase would spread over months, or even years, with the presence of long-lived radiocesium.

More importantly, despite warnings that rare events are by nature unpredictable, international (pre-Chernobyl) recommendations for accidents beyond the design basis were targeted mainly for accidents with local or regional consequences.[9] Only after Chernobyl did the IAEA (1986a, p. ii), in revising its planned publication concerning intervention levels, recognize that "the major part of the collective dose-equivalent commitment resulting from an accident will, in general, be accumulated at much greater distances." The possibility of a large collective dose at great distances from an accident was given little credibility prior to Chernobyl.

It would be a mistake, however, to assign full responsibility for the chaotic European response to the *surprise* element of the Chernobyl accident. Had the accident been of the kind envisaged in emergency planning to date, international recommendations still may not have assured a smooth and credible response. A more fundamental problem exists in translating international intentions into national or local reality. After commenting on the extensive work of national planning authorities coordinated by the IAEA after the TMI accident, Collins of the US NRC went on to say: "The problem in the US – and I dare to say in other countries – has been getting people to follow the existing guidance. They just won't do it" (Collins, 1981, p. 28).

While the fallout from Chernobyl was creating even further public distrust of nuclear power programs and the institutions that run them, the leaders of the major nuclear supplier or user countries (Canada, France, the Federal Republic of Germany, Italy, Japan, the UK, and the USA) met at a summit in Tokyo and resolved that "properly managed" nuclear power would continue to produce an increasing share of the world's electricity. At about the same time, President Gorbachev said it was unthinkable to envisage a world economy without nuclear power. Thus, international organizations were remobilized by their political leaders to prepare the world for the possibility of future nuclear accidents. Their response to the Chernobyl accident is described in Sections 5.2.2–5.2.5.

5.2.2 The IAEA

The IAEA established itself early on as the international center of activities concerning the Chernobyl accident. In early May 1986, at the invitation of the Soviet authorities, the Director General of the IAEA, Dr. Hans Blix, and two senior colleagues made a much-publicized visit to the Chernobyl site. This visit was followed in May and June by meetings of the IAEA Board of Governors to decide on a series of actions to be taken.

The accident at Chernobyl was analyzed at a Post-Accident Review Meeting convened in Vienna from 25–29 August 1986. Participants and media applauded the candid presentation of facts and background information by Soviet representatives. A summary report of the accident prepared by the International Nuclear Safety Advisory Group followed (INSAG, 1986). This report concluded that: (1) no new physical phenomenon had been identified; (2) there is a need to develop a "nuclear safety culture" in all operating nuclear plants; (3) the defense-in-depth concept must be implemented in reactor design; and (4) the importance of a satisfactory man–machine interface should be reemphasized.

The most spectacular diplomatic action following Chernobyl was drafting and adopting two international conventions in the area of emergency response. It can be recalled that following TMI, the Agency had unsuccessfully promoted an international agreement on transboundary radionuclide pollution. The Chernobyl accident provided the necessary shock to turn this draft into an agreement on the early notification of accidental releases of radioactivity with potential transboundary consequences. A second convention dealt with the provision of international emergency assistance in the event of a nuclear accident.[10]

The IAEA convention on the Early Notification of Nuclear Accidents was negotiated and signed by 51 states within six months after the Chernobyl accident. By early 1988, the convention was in operation in 14 states. Its arrival was generally welcomed by governments as a triumph of international cooperation, which would greatly improve the communication of nuclear accidents. This convention, according to some observers, however, does not go far enough in assuring that the public is informed. The convention requires that state authorities notify those states that are, or may be, physically affected by

> any accident involving facilities or activities ...from which a release of radioactive material occurs or is likely to occur and has resulted or may result in an international transboundary release that could be of radiological safety significance for another state.

This wording, as Sands (1988) points out, lets the state in which the accident occurs decide whether the accident may have transboundary effects or could be radiologically significant from a safety standpoint. This could be a serious loophole. In fact, the convention would not necessarily have required the USSR and the UK to have provided earlier and more complete information than they did in 1986 (Chernobyl) or 1957 (Windscale), although the *intent* of the convention clearly goes in this direction. In addition, the convention does not require the state to give information to the public. In the words of Sands, "The Convention is a missed opportunity to strengthen the tenuous threads of confidence linking government, people, and press in nuclear matters."

The Agency was concerned not only with improving communications after a major accident but also with ensuring a more consistent response. The draft document of guidelines on the setting of derived intervention levels for contamination of foodstuffs and environmental materials was revised and published shortly after Chernobyl (IAEA, 1986a). The Chernobyl accident also meant a 30% budget increase for the IAEA's nuclear safety activities.[11]

5.2.3 The WHO

The World Health Organization was one of the first international bodies to respond to Chernobyl. On May 6, the WHO convened an expert group meeting at its European regional office in Copenhagen to provide immediate advice to health authorities. The group focused on those areas that received heavy rainfall and where it was advised to wash fresh vegetables and to refrain from using rainwater. It found no reason to restrict travel, bar imports, restrict the use of drinking water or dairy milk, advise against breast feeding, or encourage extra hygienic measures (WHO, 1986a).

As a follow-up to this meeting, several documents were prepared which provided first-hand information on the effects of the Chernobyl accident (WHO, 1986b, 1986c, 1986d). Longer-term activities are planned, together with the IAEA and the FAO, to provide clearer guidelines for public authorities with regard to interventions and to follow the epidemiological effects of the accident.

5.2.4 The NEA

The Nuclear Energy Agency (NEA), an autonomous technical agency of the OECD, promotes cooperation among 23 participating countries on the production and uses of nuclear energy for peaceful purposes.[12] The NEA reported early on that the Chernobyl accident did not bring to light any new previously unknown phenomena or safety issues that were not resolved or otherwise covered by current reactor safety programs in OECD Member Countries (NEA, 1987a). Because of the deficiencies in the RBMK reactor's design and the difference between the Chernobyl plant and the facilities in OECD countries, no immediate modifications or regulations were considered necessary. In other words, the NEA assured Member Countries that a Chernobyl-type accident was not likely to happen in the West.[13]

In response to a survey, OECD Member Countries provided data to the NEA on ground deposition, estimates of individual and collective doses in the first year, and – perhaps most interesting – information on any countermeasures taken to reduce doses. In this survey, Austria, which does not have a nuclear industry, stands out as both having suffered the largest contamination, along with the Scandinavian countries, and having taken the most stringent measures to reduce the effects on the public (Hohenemser, 1988).[14] The NEA (1987b, p. 52) went on to explain the disparities in response among OECD countries, which, among other things, were due to the "large emphasis given to non-radiological, non-objective criteria."[15]

5.2.5 The EC

The EC is legally more empowered than the UN given its binding legislative authority. This potential power is limited in practice, however, by the political realities of achieving agreement and cooperation among Member States.

Following the Chernobyl accident, there was a lively debate at a special session of the European Parliament. Three main opinions were voiced: improvement of safety measures in the broad sense (center-right groups); a change of direction on energy policy and gradual reduction of nuclear energy dependency (socialist and communist groups); and immediate shutdown of all nuclear power stations and development of alternative sources of energy (Rainbow group). There was also considerable controversy regarding the unanimously deplored lack of information from the competent authorities. Two compromise resolutions were passed. The first, *inter alia*, condemned the way the information was distributed by the USSR and requested that the Commission report on the effects of the accident, deplored the absence of binding international rules on safety, requested Member States to cooperate with the IAEA on reporting accidents, and called for common and *binding* international safety standards and inspections. The second resolution called for immediate action on foodstuffs and agricultural products.

Measures taken by the EC regarding foodstuffs are described in detail in Chapter 4.[16] Derived reference levels (DRLs) were provisionally established by the Commission for the import and export of foodstuff to and from EEC Member Countries. Relatively low values were selected for the control of radiocesium, namely, 370 Bq/l in milk and 600 Bq/kg in other foodstuff, which reportedly were not formulated solely on radiological protection grounds (NEA, 1987b). Some countries chose to set even lower limits for importing food from Europe.

A CEC study, which assessed the environmental contamination of the Chernobyl accident in EC countries, the dose and health effects, and the usefulness of countermeasures, concluded (in contrast to the NEA study) that the countermeasures were only marginally effective.[17] There was concern on the part of the CEC that some countries had taken measures that were too restrictive considering the "corresponding to trivial levels of activity." These measures hurt certain economic–agriculture interests in Member States. In cooperation with the FAO, the CEC plans to develop reference values of activity concentrations in foodstuffs for regulating trade in the event of future nuclear accident.

5.2.6 Summary remarks

The Chernobyl accident set international organizations into motion, not only toward *preventing* a second Chernobyl, which, however, was considered unlikely in the majority of the world's reactors, but also in *preparing* national governments for the highly unlikely event of another reactor accident. This preparation has had many downstream ramifications: for example, national alert systems, school education programs, and even (in Austria) requirements on municipalities and households to finance and build shelters. Reducing accident consequences by emphasizing accident preparedness has been viewed by some as the *key* to public acceptance. Starr, for example, suggests "a mirror image reversal in the traditional attitudes of the industry." He contends that public acceptance depends on public perception of credible protection and rescue systems for neighbors of a nuclear station. Post-accident planning should, thus, be a key part of the solution to obtaining public acceptance (Starr, 1987, p. L111).

Many would undoubtedly argue that protection and rescue systems are not the key to public acceptance, although they play a role. What is clear is that after Chernobyl, the response to nuclear accidents was given more attention by international organizations than, for example, reexamination of the nuclear option or establishment of rigorous, binding safety rules backed up by an effective international inspectorate. While the INSAG report clearly emphasized the importance of preventing nuclear accidents, accident preparedness and emergency response gained added priority as witnessed by the two major international conventions following the Chernobyl accident. Growing emphasis on energy preparedness is not unique to the nuclear industry, but it is becoming increasingly important in such areas as hazardous materials transportation and natural catastrophe management. Since the cost of this preparedness generally, but not always, falls on local and national governments, this trend may shift part of the risk management burden onto the public. A question which naturally arises is to what extent industry should also share in the cost of emergency preparedness.

International organizations were also concerned with the seeming communication failures after Chernobyl and especially with the *disparate responses* of European countries to the widespread contamination. IAEA's Director General called the European response an example of poorly harmonized risk management that could jeopardize public confidence in the authorities (Blix, 1986). The Director General of the NEA expressed concern that Chernobyl "left the impression that the machinery of international coordination had not worked very well" (Shapar, 1987).

Harmonization and *standardization* of emergency response, with all its implications for communication and interventions, thus became one of the chief post-Chernobyl occupations of international agencies. Ironically, quite opposite traits of emergency response, namely, flexibility and national (and local) discretion, were considered desirable in the aftermath of the TMI accident. An accident planner (Martin, 1981, p. 28) at the post-TMI IIASA meeting noted that "twenty years of experience in this field have shown me that safety cannot be assured by administration. There is a limit to how large a role plans can play." This view was reinforced by Otway:

> My experience in planning for this sort of accident is that the more specific the plan, the more likely it is to be wrong. We seem to be tacitly assuming that emergency planning is a good thing that one can't get too much of. ...At what point are we involving too much effort, perhaps even distracting ourselves from the more important issue of preventing accidents? [Lathrop, 1981, p. 29]

This flexibility was reflected in the pre-Chernobyl (post-TMI) ICRP-IAEA-WHO advice, which recommended that nonstochastic effects be avoided and that significant stochastic risk to individuals be limited according to cost-benefit principles. Yet, even this rather general and open advice was not always followed. The NEA report showed that many countries placed importance on reducing the collective dose and did not concentrate on critical groups or those individuals most at risk.[18] In fact, Luxembourg and the Netherlands assumed that no group of individuals was significantly more at risk than the general population.

The fact that countries deliberately chose a policy counter to international recommendations in place at the time of Chernobyl suggests that even flexible recommendations cannot always be sensitive to the realities and necessities of political decision making. The ICRP-IAEA-WHO advice to place high priority on reducing the highest risks appears natural and "objective" if the goal is solely to "reduce risks." Like other areas of policy response, in reacting to nuclear emergencies, public authorities are sensitive to a host of social and psychological factors. Surprises, uncertainties in data, differences in political styles, institutional diversity, and public demands will naturally and inevitably influence response (Wynne, 1983).

While harmonization efforts in the form of improved communications, warning systems, and internationally accepted DILs are clearly desirable, they may not lead to a fully harmonized response in the event of another nuclear accident. Nor, perhaps, should they. An adequate response to the next nuclear surprise may depend on national and local flexibility. What appears as a chaotic international response may, thus, have hidden merits when viewed in the perspective of the diverse political cultures and needs of the responding countries. The challenge is to balance local flexibility and international consistency.

Complete reliance on international guidelines and rules is impracticable at the national level. There is also a danger of overdependence on and overconfidence in these international rules. The *process* of developing emergency response guides and plans has the added effect of creating knowledgeable and responsible persons and institutions within the national setting. Knowledgeable persons may be more important than international documents in the aftermath of an accident, although clearly the former can appeal to the latter. In addition, these persons and institutions are accountable for the success or failure of their policies. Although international institutions are assuming greater responsibility for safety and response measures, they are not fully accountable for the outcome of these policies – which are usually adopted and implemented at a more local level. Again, the challenge is to balance international and national responsibility and accountability.

5.3 An International Nuclear Safety Regime

The important question is, Can international organizations, especially the IAEA, meet their increasing nuclear-control responsibility by genuinely contributing to international nuclear safety? This question is posed at a time of fresh optimism with regard to the credibility of the United Nations as a centralized forum for world environmental policy following widely acknowledged agreements on transboundary pollutants coordinated by UNEP. As Carroll (1988) points out, however, the real test of these negotiated agreements will be in their implementation. The UN cannot enforce compliance, and skepticism about the rationality of a centralized "global decision maker" still exists. In addition to general doubts about the effectiveness of the UN, the IAEA's safety role will hinge critically on three factors: the political will on the part of Member States to allow increasing international intervention for nuclear safety; the inherent capacity of the IAEA to control or even oversee global nuclear operations; and the ability of the Agency, in light of its established role in promoting nuclear power, to generate public credibility as a safety watchdog.

5.3.1 Political will

Chernobyl is viewed by some as the necessary stimulus for a new international safety regime based on common interest and an authoritative global institution. In the words of Ramberg (1987, p. 325), "There will always be risks, but the risks can be minimized by authoritative institutions ready, willing and able to apply preventive medicine." Others argue that the IAEA cannot effectively defend international nuclear safety so long as its nuclear safety standards remain mere recommendations. Many hope for more political commitment or political will from Member States to agree to binding safety standards and inspections. Since the political will was demonstrated in the case of the Non-Proliferation Treaty (NPT), this experience is examined below.

The willingness of nations to allow extra-national entities to scrutinize a most sensitive industry has been viewed as remarkable.[19] It is the first time in history that sovereign states have allowed an international organization to perform inspections on important installations within their territories. This political will has been motivated by two factors: the desire on the part of "weapon" countries to limit proliferation and the desire on the part of "non-weapon" countries to develop their civilian nuclear programs. The idea is to spread the benefits of nuclear power worldwide as a bonus to countries that voluntarily decide to renounce nuclear weapons. The promotional or technical assistance activities of the Agency are therefore critical for keeping the safeguard system intact.[20] It has been argued that the IAEA has done a good job in stopping proliferation, given the circumstances, but that the circumstances themselves may make it impossible to maintain an impervious institutional barrier (Wynne, 1988). At any rate, the Agency's power to bargain compliance with NPT in exchange for technical assistance is wavering, as developing states acquire their own technical know-how.[21]

The politically imposed limits on IAEA's powers to control proliferation are often ignored or misunderstood. The IAEA can only verify information submitted to it on national nuclear programs. It cannot *demand* access of information, and thus does not have anything like the powers of an "international policeman." If the IAEA is failing with respect to this exaggerated model, it is more a reflection of missing political will among Member States than it is of the IAEA *per se*. It is the Member States and non-signatories of the NPT who have invested the agency with what are actually quite limited powers. As the NPT bargain shows strains, it is even less likely that sovereign states will agree to nonpartisan inspections of nuclear power plant safety or to binding international safety regulations. These would have to be far more extensive than they are for materials diversion. In fact, the record of requests for IAEA inspection teams has not been impressive. From 1983 to 1987, some 23 OSART missions were carried out. Inspections increased after Chernobyl (5 in 1987 and 12 to 15 in 1988) and included, for the first time, requests from East European countries. Although OSART findings are summarized to be used by other plants, the actual missions do not constitute a significant proportion of the 380 or so operating nuclear power plants in the world.

National governments are also reluctant to grant an international body the power to impose binding nuclear standards. This power would restrict their operating flexibility and could have undesired consequences on the commercial viability of national nuclear industries. The nuclear industry, which is concentrated in only a few supplier countries and is characterized by very few competing technological designs, is especially sensitive to international safety standards. A recent discussion to limit the whole body radiation exposure, in the case of a severe nuclear accident, to persons at the site boundary illustrates this sensitivity. While light-water reactors could meet the requirement of 25 rems recently recommended by the Electric Power Research Institute (EPRI, 1990), they would have trouble meeting lower limits that could, however, be met by gas-cooled reactors (Gas-Cooled Reactor Association, 1989). An international standard below 25 rems could seriously jeopardize the future of light-water reactors.

5.3.2 Resources

Constitutionally, the UN has no enforcement power and has to operate by moral persuasion more than legal sanction. Yet some argue (e.g., Pitt, 1986) that these existing channels of influence have been limited by political forces and bureaucratic ineptitude. Even the more independent UN agencies such as the IAEA have not escaped these difficulties. Suggestions for increasing the IAEA's safety role, e.g., an Agency emergency response capability, an international nuclear safety inspectorate, or increased resources devoted to OSART missions, would require massive increases in the Agency's resources.

The IAEA's budget for safeguards and nuclear safety programs rose from \$10.2 million to \$42.7 million during the 10-year period from 1977–1987; the \$11 million budget for safety programs increased approximately 30% (to \$14 million) after Chernobyl. Still, these funds are minuscule compared with the multibillion dollar international nuclear industry.[22] Several countries (including the USSR, the USA, and the Federal Republic of Germany) have requested OSART missions following Chernobyl; however, IAEA's limited resources permit only cursory inspections. For lack of funds, even the Director General of the IAEA is pessimistic about the Agency's role in an international nuclear safety regime:

> Although the IAEA has and will retain a central role in international co-operation, it has no mandate and cannot become an international supervisory organ to assure nuclear safety. Governments will retain their present responsibility and competence.
>
> It is arguable that co-operation between all who are concerned with nuclear safety is already better than it is in other industries. But more needs to be done before we can claim that there is such a thing as "an international nuclear safety regime." [IAEA, 1987]

If the IAEA were given the ingredients of a political mandate, legal powers, and vastly increased resources, still a cursory look at nuclear safety as a technical problem indicates serious practical limitations for an international safety regime. Nuclear safety is a problem requiring almost full-time interaction between industry and regulators, from the earliest design phases right through to eventual plant decommissioning. Each national system's technical commitments to reactor types, fuel-cycles, data on operational experience, detailed regulatory mechanisms, etc., are closely linked to a national network of established institutional practices and decision-making relationships. Even if an international body had unlimited powers of access and manpower, it would be difficult for it to become meaningfully involved at a technical level in the national safety regulation systems of the 26 countries currently with nuclear programs.

This problem, combined with the questions of authentic political will, leaves the possibility that the diffuse but real public pressure to improve global nuclear safety could generate initiatives that are more symbolic than practical. This leads naturally to the question of credibility, which has emerged as a recognized issue only recently, alongside the realization that without "public confidence" the industry is crippled.

5.3.3 Credibility

Disregarding resource problems and other barriers to implementation, some suggest that the IAEA might overcome political resistance to an expanded watchdog role by appealing to the benefits of added credibility that an authoritative international institution would give national nuclear programs. In the words of Fischer (1986, p. 48), "Governments might help to reestablish public confidence in nuclear power if the standards they applied had international authority and if they were to strengthen the IAEA's capacity to provide authoritative advice about the safety of their operations."

Appealing to the IAEA as a means of increasing public confidence in the safety of nuclear power begs questions about its existing public image. There are some potential problems here. While the Agency has shifted emphasis away from promotion toward safeguards and nuclear safety, the public and critics of nuclear power may not place confidence in an international body with the mandated purpose of promoting the nuclear industry. The more the IAEA asserts political and intellectual independence in search of public credibility, the less credible it may become with its members, thus threatening the fragile negotiating influence that it has. A similar dilemma confronts national regulatory bodies, but at least they deal in a single culture. They can and do carefully play on public concerns to encourage better standards. This is far more difficult for an international body with many such clients and more diffuse and distant publics.

The already fragile credibility of nuclear regulatory bodies, as well as the IAEA, was put to a further test at the time of the Chernobyl accident. The heretofore messages to the public that the chances of a major nuclear accident were minuscule had to be explained in light of two serious accidents in the span of only one decade. As discussed at length in Chapters 6 and 7, there are many ways of communicating risk information to the public. Chernobyl illustrated the double meanings and seemingly conflicting perspectives that can be given to small probability risks spread over a large population. For those consequences outside of the Ukraine and Byelorussia, the *small individual risk* (the seemingly insignificant increase in cancer mortality) throughout Europe could be emphasized or, alternatively, the large population at risk could be emphasized with the *significant number of expected future fatalities.* For each individual, these risks are *small*; however, for a large population, the consequences are *large.* A balanced communication would emphasize both. This balance was apparent in the rather careful explanations of the Chernobyl consequences in the USSR offered by the IAEA's Director General following the accident:

> It has now been authoritatively estimated that the collective dose could give a maximum of 5,000 to 20,000 additional cancers in the Western part of the Soviet Union over the next 70 years. Using the same method it is estimated that there will be some 100,000 cancers from the normal background radiation. To give a perspective – we can forecast with some certainty that there will be some 10 to 15 million cancer deaths in the same population over the period. We can thus conclude that the medical consequences of the accident were severe, *even though they did not reach the level of the chemical industry accident in Bhopal in India.* [Blix, 1986, p. 9]

This quote illustrates two perspectives on population risk data: (1) contrasting the probabilities with other common risks or background risk and (2) comparing the expected consequences to those of other accidents. While both perspectives are valid and, in this case, reassuring, there is still a danger that they may be interpreted as trivializing the accident. In fact, such perspectives are not generally given for accidents that result in immediate fatalities. Society's callousness to future "statistical" deaths led the US NRC (1987, p. 4) in its evaluation of Chernobyl to remark, "Extra cancers calculated from radiation exposure are real, not imaginary or merely theoretical." The theoretical nature of the Chernobyl consequences have changed rather dramatically only four years after the accident. Rising cancer rates in parts of the Ukraine and Byelorussia have prompted officials to evacuate many areas. The public is naturally asking why these risks were not foreseen earlier.

In contrast to the balanced perspectives given to the Chernobyl consequences immediately after the accident (although one can question the sensitivity of the perspectives chosen), a later publication by the IAEA to mark the second anniversary of Chernobyl was far less balanced:

> Despite some public perceptions about an impending global-scale catastrophe, the Chernobyl accident resulted in no human fatalities outside the plant area; the 31 deaths and nearly 300 injuries involved plant workers and fire fighters at the accident scene. [IAEA, 1988, p. 1]

No mention was made of the statistically expected fatalities throughout Europe.

This selective approach on the part of the IAEA is not surprising given its historical mission of promoting the development of nuclear power. However, it will hardly help the Agency to become accepted as a credible watchdog for nuclear safety by many national politicians, activist groups, and a skeptical public. Even worse if, as argued by Wynne (1988), perceptions of risk are grounded in the credibility of the institutions that are supposed to control the risks, then more intervention by the IAEA might even increase the apparent gap between expert and public perceptions, unless a critical review of these underlying problems is undertaken.

The post-TMI Kemeny Commission identified deep-seated organizational mind-sets as undermining the full and critical regulatory independence needed to ensure safety and public confidence. In national settings, where this structural or intellectual "capture" problem has existed, relations between regulatory bodies and industry have been altered to create more direct oversight by political representative bodies. In the USA, for example, President Carter established a Congressional Nuclear Oversight Committee. While such arrangements have their limitations, mutual accountabilities of regulator to industry, and vice versa, have been somewhat changed. In the IAEA's case, a key structural problem is that the national reference groups to whom it relates, and with whom it establishes credibility, are not political representative institutions (such as special parliamentary committees on energy) but national administrative bodies. For the IAEA to shift away from the structural conflict of interests in regulation would require accountability to national public opinion reflected in politically representative institutions, which would render its relations with national nuclear industries more complicated and difficult. This is arguably a necessary (though not sufficient) condition of its wider public credibility, and only exposes the depth of the obstacles confronting an effective and credible international safety regime.

5.3.4 Developing an international safety regime

Solutions to many risk problems need international coordination and action; yet most transnational institutions lack the authority and power to implement their requirements directly. Especially institutions with many members trying to tackle global problems have proved to be weak in reaching effective agreements.

Perhaps more progress in coping with transboundary risks has been made through bilateral and multilateral agreements. Majone (1985) argues that the more promising form of international regulatory institutions will be based on functional regionalism, where the scope and authority of international bodies are limited to specific issues in some geographically and functionally demarcated area. A leader-country approach is advocated, in which a few key countries with relatively homogeneous interests take regulatory actions that "pull" or "push" other countries to follow.

The NEA of the OECD might be such a regional, functional institution, although it has, as yet, no real regulatory powers. The EURATOM framework within the EC might be thought to have many points in its favor. It exists within a genuine international framework in which the sovereignty of Member States yields to a regional power with authentic legal sanction in many environmental areas. However, EURATOM has been one of Europe's least successful regulatory institutions, ironically in a sector with most public demand for regulation. Short of such an international institution, several bilateral agreements are being negotiated as countries become aware of nuclear risks across their borders. This type of cooperation includes consultative agreements with regard to nuclear safety, radiological protection, physical security, and environmental acceptability of proposed or existing plants. Examples of such bilateral and regional agreements include the arrangement among Nordic countries and the agreements between Austria and Czechoslovakia, Argentina and Brazil, and Finland and the USSR.

These agreements can best be reached when countries share common interests and risks, that is, between countries with similar nuclear ambitions and nuclear technology. Where this is not the case (for example, witness Austria's conflict with the Federal Republic of Germany over its ambitious breeder program), confrontation is more likely than negotiation.

This developing patchwork of bilateral agreements – or incremental, regional policymaking – can have significance beyond the formal words and obligations. As Gerlach and Rayner (1988) have proposed with respect to the climate-change issue, effective management decisions need not be made only through formal treaties between nations, although such agreements may have significant symbolic value. Decisions can also be taken by a process of formal and informal interactions between very different people and organizations. Informal networks can be developed that lead to government or institutional actions that are harmonious but not part of any international agreement. In short, a "regime" is built. Gerlach and Rayner define a regime as a social network coordinated by shared designs for action and interaction, and by shared interpretations of the problem to be solved. Participants interact in loose flexible networks rather than tight hierarchies, and the shared principles and procedures often are informal, implicit, and more flexible to variable conditions and criteria for effectiveness.

With regard to nuclear safety, such a networking process is well imaginable, even underway and coordinated to some extent by the IAEA. Webs of scientists, industry specialists, concerned citizens, and regulators are being spun across borders, and these webs are the beginning of an international safety regime, less formal but potentially more effective than the conventional concept.[23] Those examining the lessons from both the TMI and Chernobyl accidents have articulated the importance of developing a nuclear safety culture, or shared perceptions of the importance of safety measures during day-to-day operations. The point of such a concept is that it could be more widely based than centralized, with formally standardized (though in practice, unevenly implemented) frameworks and obligations. Such an approach may allow for more public and work force identification and access. However, whether it is ultimately compatible with nuclear technology remains an open question.

A word of caution should be voiced. One important element of a regime is that the principles, norms, and rules, whether explicit or implicit, are *shared and understood by the participants* about what is legitimate, appropriate, or moral (Gerlach and Rayner, 1988, p. 52). The nuclear power issue is characterized by opposing views of the problem and legitimate solutions. A developing international safety regime, composed of different national organizations, sits with a growing sense of confrontation and insecurity alongside a second (increasingly organized and powerful) antinuclear regime, which does not believe that nuclear power can ever be acceptably safe, on both environmental and weapons proliferation grounds. Hitherto, it has been the political articulations and criticisms from the latter regime, largely at national levels, that have forced more critical attention to safety from the more formal pronuclear safety regime.

At an international level, the evolution of perhaps overlapping bilateral and regional agreements among different organizations circumvents more inflexible models of control. With regard to the nuclear safety regime, the bilateral treaties are important symbols of this network. The IAEA can and does play a central role as a forum for this nuclear safety network. As Gerlach and Rayner (1988, p. 74) observe, "Most who are directly connected with [the UN] agree that its real value is not in the formal debates conducted in the General Assembly or Security Council Chambers, but its role as a vital node for international networking."

This informal, networking model leads to a number of issues with regard to the safety of nuclear energy on a global scale. For instance:

- Will the emergence of a more flexible international safety regime make it more or less difficult to sustain public pressure for the practical improvement of standards and safety? Or will the properties that create extra flexibility also make the overall system less transparent and accessible?
- The nuclear industry is a global business with patterns of ownership, commercial interest, power, commitment, and loyalty reaching across national boundaries. If regulatory regimes are to reflect the structure of the technology, equivalent patterns of transnational command and authority are implied. Can these be achieved via a network of *ad hoc* regional agreements and commitments? The alternative is a more formal global regulatory institution, unfortunately with little relationship to a genuine constituency of public opinion.

5.4 Summary

- From an international perspective, the accident at Chernobyl was anticipated and prepared for, at least in the sense that international guidelines and recommendations for dealing with a major nuclear accident had been put into place after TMI.
- The TMI accident had changed industry's view that an accident was not the central problem of nuclear energy. Since more could be done to improve the largely ignored area of emergency response, then more should be done – even though the probability of a major nuclear accident continued to be considered minute.
- At the time of Chernobyl, emergency response was securely in the hands of national authorities. The international community had prepared guidelines on planning and interventions, as well as some nonbinding recommendations on safety (targeted mainly to developing countries). In addition, international authorities had anticipated transboundary effects but, for lack of political momentum, made no preparations for such emergencies.
- The Chernobyl accident changed this, and the international response was in some ways dramatic. The EC banned the import of certain contaminated foodstuffs, and important international agreements were concluded by the IAEA in areas of emergency communication and assistance. The clear

emphasis was on establishing the conditions for more harmonized political actions.

- Because of complex institutional and political considerations, some countries deliberately chose to ignore even the flexible international guidelines on interventions in place at the time of Chernobyl. This complexity is a natural part of political decision making, perhaps the more so after a national emergency, and will inevitably limit attempts at harmonization. A seemingly chaotic response to a wide-scale nuclear accident may mask the underlying value of national discretion in meeting the diverse needs of different political cultures.
- With regard to preventing future nuclear accidents, as opposed to responding to them, Chernobyl had little effect on the role of the IAEA which was already committed to prevention. However, the IAEA still has no binding regulatory and inspection powers, and a limited budget for nuclear safety. Nuclear accident preparedness, as well as preparedness for other low-probability accidents, raises the issue of industry's obligation to contribute to the expense involved.
- The unique feature of the nuclear transboundary issue is the existence of a functional, international body – the IAEA – that is concerned with the civilian uses of nuclear technologies. The IAEA's contribution to global nuclear safety is constrained, however, by the lack of political will on the part of Member States to allow more meaningful and binding international interventions for nuclear safety, the IAEA's limited staff and budget to control global nuclear installations, and the restricted ability of the Agency to establish its credibility as an authoritative control body in light of its mandate to promote nuclear power. The EC has considerably more binding powers to regulate the nuclear industry in Europe, but its EURATOM initiatives, to date, have been disappointing.
- In the absence of an authoritative global or regional institution with binding and effective regulatory powers, less visible "regimes" made up of networks of scientists, industry representatives, regulators, and perhaps citizens are developing to further nuclear safety and, in part, are being coordinated by the IAEA. Bilateral agreements between countries can have significant symbolic value, and international agencies can contribute a useful networking service. Crucial aspects of such regimes, however, are shared principles, norms, and rules on the part of the participants, which make it unlikely that they can accommodate persons and groups with fundamentally opposing views on the future of nuclear power.
- The real lesson of the Chernobyl accident may lie in triggering international political recognition of a shared global responsibility for the safety of nuclear technologies. The question of whether this recognition leads to an international nuclear safety regime that genuinely contributes to

worldwide nuclear safety remains unanswered, although it is not likely that such a regime, if it develops, will be led by an authoritative, international institution. Our international institutions and treaties, *alone*, cannot, as Carroll suggested, close the gap between the direction of our diplomatic efforts and the direction of the environment. This holds equally true for global nuclear safety.

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Notes

[1] Scientists express an extraordinary range of calculations about the long-term effects of Chernobyl: the low being 210 deaths (Wilson, 1986) and the high, 1 million deaths (Sternglass, 1986). A US government study projects 14,000 cancer deaths (US NRC, 1987).

[2] Recently, UN agencies have taken responsibility for administering international treaties for the control of ozone and climate-threatening gases.

[3] In 1974, the IAEA projected that 4.45 million megawatts of nuclear power would be in place in the world by the year 2000. In 1987, its predictions were 505,000 megawatts. In the USA, where costs of nuclear power have in many instances become noncompetitive, a new plant has not been ordered since 1974. In France, which gets two-thirds of its electricity from nuclear power, Electricité de France has a debt of $32 billion, exceeding that of most developing countries (Flavin, 1987).

[4] Government-sponsored assessments in the USA and the Federal Republic of Germany showed that core-damaging accidents could be expected to occur about once in every 10,000 years of reactor operation. The WASH-1400 report estimated that for the 200 nuclear power plants operating in the USA, the probability of an accident resulting in 10 or more fatalities to be about 1 in 3 million, and for 100 or more fatalities to be about 1 in 10 million. From a cost-benefit perspective, assigning a benefit of $1 million to saving a life (not uncommon for cost-benefit purposes in the USA), preventing deaths from an accident otherwise resulting in 100 or more fatalities would be worth an expenditure per plant of about 5¢.

[5] In 1958, a manual on the safe handling of these substances was completed, followed by other Safety Series publications such as ***Regulations for the Safe Transport of Radioactive Materials*** (1960) and ***Basic Safety Standards for Radiation Protection*** (1963). In 1963, the Agency organized a symposium on the siting of nuclear power plants, one of the first major activities concerning reactor safety.

[6] The ICRP is an independent scientific body based originally on the International Congress of Radiologists, from whom it drew its members. After World War II, it was reconstituted as a self-appointed body of scientists from fields connected with radiology. The ICRP has always set recommended protection standards,

involving social judgments of acceptable risk, as well as making scientific estimates of the risks. It has been criticized for being accountable only to itself, as well as being informally too close to the nuclear industry and radiology. Recently, after charges of being slow to recognize new scientific evidence on the health effects of radiation, some national authorities have broken rank and made recommendations that are stricter than ICRP recommendations.

[7] EURATOM has suffered from problems of national sovereignty and a shifting energy context. Its main functions include a safeguards program (which has been made partly redundant by the IAEA's program), the coordination of research and development, and a program concerned with assuring equal access to nuclear supplies. Its lack of teeth has been exposed by a recent controversy about its inspectors' inability to access the Sellafield reprocessing plant in the UK, the largest producer of sensitive nuclear materials in Europe.

[8] In Finland, the application on a fifth nuclear power station was shelved, and the newly elected government pledged not to expand the nuclear program.

[9] According to IAEA safety philosophy, technical provisions are made at the design stage for the control of accidents within that design basis. Only for accidents beyond the design basis are off-site measures necessary to limit the damage (INSAG-3, 1986).

[10] Following consideration by the IAEA Board of Governors, these two conventions were adopted by unanimous resolution at a special session of the IAEA General Conference in September 1986. Both are now in force. A computerized Emergency Response Unit has been set up, which will be notified when an accident occurs. Use will be made of the World Meteorological Organization's Global Telecommunication System for rapid notification and exchange of information in a radiological manner.

[11] This has to be allocated to operator training programs; expansion of the Agency's OSART Program; the management of severe accidents and emergency response; the man–machine interface; probabilistic safety assessment; and advanced safety technology.

[12] Formed in 1958, the NEA helped to stimulate the European nuclear industry and to lay the groundwork for EURATOM. The budget of the NEA is approximately $10 million. Concerned with safety and regulatory issues as well as with the scientific and economic aspects of nuclear energy, the NEA is, at present, the only forum where Western developed countries can discuss technical problems and exchange information with each other.

[13] The report concluded that the design of the RBMK reactor is deficient, although the design was well understood and was considered capable of providing protection against events that had been considered on the design basis. The report also pointed to the Soviet problems of implementing safety measures.

[14] The *average* individual effective dose equivalents range from a few microsieverts or less for Spain, Portugal, and most of the countries outside of Europe to about 0.7 millisieverts for Austria (although the doses in many cases were far greater). Austria reportedly reduced the average individual dose received by as much as 50%, whereas, e.g., Norway reported 33%, Sweden 17%, Turkey 11%, and the UK 1%.

[15] The report also cites the large uncertainties in impacts, the use of differing assessment methodologies, and different assumptions on population characteristics as contributing to the varied responses.

[16] As described in Chapter 4, the Commission acted on 7 May under its own decision-making process by temporarily suspending the importation of certain meats from seven countries with territory within a radius of 1,000 km from the site of the accident. The importation of other foods was later restricted.

[17] In a few countries, the restriction on food consumption was effective in reducing doses to the most exposed individuals up to about a factor of two. Throughout the EC, however, countermeasures were estimated to have reduced the collective effective dose by only about 5% (Morrey *et al.*, 1987).

[18] Countries such as Austria, the Federal Republic of Germany, and Scandinavian countries; the UK, however, concentrated on high-risk groups.

[19] The safeguard system itself has been subject to controversy and to increasing stress, yet there is little question that the safeguard system has established the Agency's credibility and assured its survival.

[20] The IAEA has dispensed nearly $150 million worth of equipment to advance the introduction of nuclear applications and to facilitate hands-on experience in training and an additional $25 million in the form of research contracts (Scheinman, 1988).

[21] Funding for promotional activities at the IAEA has been modest and has remained fairly static, rising from $2.9 million in 1977 to $4.2 million in 1987.

[22] Critics of the IAEA claim that industrialized nations have little interest in contributing large resources to the IAEA for activities outside of the safeguards program and that the few million dollars spent on nuclear safety only give an illusion of a meaningful activity (International Nuclear Safety Advisory, International Nuclear Reactor Study, 1986).

[23] For example, the World Association of Nuclear Operators (WANO) was founded in 1989 with the purpose of enhancing the safety of nuclear power stations. It has four regional centers in Atlanta, Paris, Moscow, and Tokyo.

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Chapter 6

Perception of a Secondhand Reality

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This chapter begins by defining perception in relation to its social determinants, including the beliefs that filter experience and give meaning to it. The Chernobyl event is then described as a "secondhand reality," shaped and framed by the mass media. Methodological problems are then discussed. Finally, the main issues of public concern that came to the fore in connection with the Chernobyl accident are identified and discussed. These include the decision-making procedures, competence and reliability of decision makers, and ultimately the credibility of democratic institutions.

6.1 Defining Perception

6.1.1 The filter of beliefs

We perceive through our senses, but what we perceive (and how we perceive it) is selected through a series of both personal and social filters, having to do with our criteria, values, beliefs, personal inclinations, social milieus, etc. Beliefs originate in experience. Experience is considered here in a very broad sense; literally anything that people may encounter, both objectively and subjectively.

Experience is information individuals get – episodes they go through or events they observe. It is also thoughts they have, intellectual connections they make. Thus, beliefs may be also inferential: not grounded in objective experience, but rather derived from experiences that have little or nothing to do with the object of the belief. For example, phobias (fears of certain objects or actions) may originate in experiences that do not directly concern such objects or actions. In a similar way, beliefs about technologies may hold even in people that have no direct contact with them.

Gregory, a student of the physiology of perception, has suggested an analogy between perceptions and scientific hypotheses. He assumes that perceptions have no direct relation with the world and are often incongruent with one another and with what is conceptually accepted as true. Moreover, perception proceeds from unconscious inference processes, not always controlled by the mind. From these and other assumptions, it follows that data cannot be equated to what physically exists. Rather, data represent variables or events according to a code (Gregory, 1984, pp. 132 and 134).

Even if the overlapping of perception with belief is not totally appropriate, for the purpose of this chapter we will treat the perception of the Chernobyl event as a set of beliefs originating in or reinforced (in different social groups) by the experience of that event, and reaching far beyond it. This seems at the moment the best, or at least the most effective, way to define perception of the Chernobyl event for the purpose of this inquiry. If no definite answers can yet be provided, we believe that at least the right questions can and should be asked.

As Otway (1988, p. 407) has appropriately pointed out, people do not perceive abstractions such as risk; rather they perceive specific phenomena and events. Indeed, most recent research trends in risk analysis tend to accept that an individual's perceptions, beliefs, and attitudes with regard to modern technologies are made of several factors of which the so-called objective risk is just one. Therefore, questions such as How do people define risk? How do they feel about it? What amount of risk is acceptable? are gradually replaced by questions such as What is involved in people's perception of a technology? Why and how do they judge it acceptable?

6.1.2 The social determinants of perception

The social dimensions of risk perception have recently attracted the interest of anthropologists and sociologists (see Nelkin, 1985; Douglas, 1986 and 1987; Drabek, 1986; Rayner and Cantor, 1987; Wynne, 1987). These scholars have argued that the perception of risk may depend less on the nature of the danger than on the political, cultural, and social values of the subject.

According to Douglas (1987) – the foremost proponent of this approach – it is the social system, the ideological premises of a group or of a society, that shapes perceptions of risk. Risk perception can also reflect institutional arrangements, social situations, and political relationships (Nelkin, 1985).

In short, the sociological and anthropological approaches assume that "interests and biases of different groups and the social situations in which they are involved influence their perceptions of risk and their strategies of management and control" (Nelkin, 1985, p. 17).

Sociological studies concerned with the perception and the management of industrial risk have shown that the definition of risk is a conflictual process inside society, which involves a large variety of groups: scientists, policymakers, regulators, company doctors, lawyers, journalists, manufacturers, administrators, and so on (Hilgartner, 1985). The perceptions and beliefs of such groups reflect different values, economic stakes, professional ideologies, political preferences, etc.

Thus, it clearly appears that risk is not only a technological matter, but also a social and political one. Risk is a social product resulting from scientific and technological issues inside society and from social, political, and cultural values. Such values shape the perception of different groups and also influence decisions about different forms of risk regulation and management.

6.1.3 Objective versus perceived risk

If the approach sketched above becomes widely accepted, the long-standing controversy between objective and perceived risks is to be totally dismissed. Indeed the discussion can no longer be restricted by the fact that technologists know real risk and lay people rely on subjective impressions. Both technologists and the public have perceptions, beliefs, and consequent attitudes with regard to modern technologies.

The difference consists in the fact that the former's beliefs tend to be shaped primarily on the basis of scientific and technical data, probability of risk, technical measures of safety, etc., the latter's on the basis of different criteria, although not as easy to express in quantitative terms or to investigate. This difference reflects diversities in education, group culture, reference groups, social networks; that is, it reflects social diversities.

It is not, therefore, that technologists' views are wrong, nor are the public's; they are only framed differently. The theory of relativity applies to the social as well as to the physical world. To progress to a higher level of understanding, one has to be able to take different points of view and to consider them *not* as antagonistic, but as possibly understandable in a wider frame of reference.

6.2 Perception of Chernobyl

6.2.1 Chernobyl as a technological mass emergency

We define Chernobyl as a mass emergency in that many people were involved in a potentially dangerous situation of environmental stress that could debouch into a disaster.

Scholars in the field labeled "sociology of disasters" tend to agree that social factors, besides physical ones, must be part of the definition of disasters and mass emergencies. A widely accepted definition of disasters is that they are social events, observable in space and in time, in which humans and social systems have to face the upset of everyday activities resulting from the impact of an agent or from the perception of a threat that cannot be controlled directly and completely by existing social knowledge (see Kreps, 1984). It is generally recognized that the same physical agent may turn into a disaster in one society but not in another (for an excursus of literature see Drabek, 1986).

Despite the widely held belief that a disaster triggers a big change in the society, many researches have shown that social, political, and economic dynamics, both in the immediate post-impact and in the long term, develop according to the "principle of continuity" (Quarantelli, 1978).

Neither disasters nor mass emergencies occur in a social vacuum, rather they assume their peculiar features depending upon the characteristics of the preexisting social organization. Many researches have shown that the preexisting economical, social, cultural, and political characteristics of the community greatly determine both the individual and the societal behavior during the phases of response and recovery, i.e., the way crises are managed.

In short, when a hypothetical hazard becomes a mass emergency, a real present danger, we can observe the way in which different societies, communities, organizations, groups, and social and individual actors define and perceive the situation that they must face: the different levels of involvement and responsibility and the different tasks and roles. At the same time, we can recognize the latent dynamics that in the pre-disaster situation were implicit.

In analyzing the behavior of different actors in relation to Chernobyl, we will try to describe how decision makers, scientists, economic and social actors, and the public perceived the event; how they defined and responded to the situation of a nuclear emergency. We are confident that such an analysis will contribute to understanding the way risk perception shapes up within society, and we hope that, in the long run, risk perception will be more seriously taken into account by policymakers involved in risk management.

The first step in our analysis is to outline the rather peculiar nature of the Chernobyl emergency. Issues to address pertain to the kind of facts, experiences, and stimuli upon which people based their perceptions of the Chernobyl accident. On what data did people rely for defining the event and for developing their beliefs about it?

Chernobyl, as with most technological emergencies, displayed different features from natural ones (Quarantelli, 1981; Cuthberston and Nigg, 1987). In fact, technological disasters are often characterized by the absence of a clearly definable and perceptive impact phase; by an unpredictable evolution, length, and seriousness of danger; lastly, as in the case of a nuclear emergency, by the lack of an immediate and visible physical damage. Therefore, a technological emergency is often characterized by a high level of uncertainty that influences both technological and social emergency management (see Quarantelli, 1981; Lathrop, 1981).

When effects are not immediately visible, tangible, or ascertainable within a limited period of time and a circumscribed space, social response in terms of decisions and communications takes on a central role in shaping the event. The decisions that implicitly define the situation and entail the ways of coping with it and the actions carried out by different social and political actors become the complex scenario in which social perception takes shape.

6.2.2 Chernobyl as an "information catastrophe"

For the Chernobyl accident, the definition of "information catastrophe" has been suggested, since its "only and real image was the one broadcasted by the media" (Lombardi, 1988). Indeed, all over Europe – except the immediate area – the perceptions of the public, and likely of most technologists, social scientists, and decision makers, *at the time of the event* were shaped mainly by the information provided by the mass media, with its peculiar content and structure.

By no means does this mean that it was false, bad, or inaccurate information. That is not the issue here, and moreover those who analyzed the print media in relation to the Chernobyl accident concluded that they did "a fairly good job" (see Otway, Chapter 7).

At issue is simply the fact – neither good nor bad, just a fact – that people's perceptions were shaped mainly by media information. Physical data and any other kind of information had all the same level of reality, a symbolic level constructed upon communication processes widely dominated by the media. The public had no way of accessing information except via the messages and images conveyed by the mass media.

The media became the field of social relations, the ground where different actors voiced their opinions, beliefs, requests, etc.; where conflicts emerged; where negotiations were conducted. In synthesis, the media brought to the fore not only the results of the decision process (directives, approved measures, etc.), but the decision process itself, with its multiplicity of actors, uncertainties, compromises, and so forth.

To some extent, this is true for any kind of emergency, e.g., one created by a natural disaster, by a political crisis, by an epidemic. "Public behavior develops . . . within this well-defined communication field where events are dealt with at an exclusively symbolic level, beyond the physical impact of the disaster" (De Marchi and Ungaro, 1987, p. 130). What is peculiar to the Chernobyl case, however, is the overwhelming role held by the mass media in defining the communication field within which boundaries of the event became symbolically relevant.

6.2.3 Media's secondhand reality

In the early 1960s communication research started to claim that our reality is a kind of "secondhand reality" (Lang and Lang, 1962), insisting on the importance of the media in shaping and framing it.

Since the time of the so-called "hypodermic needle theory" (or "bullet theory") – which saw the receiver of media messages as an isolated, atomized, almost nonsocial, naive "victim" – much more sophisticated theories have developed. In early empirical research, the importance of personal influence and relational networks was recognized.

The model derived from Shannon and Weaver's mathematical theory of communication (1949) – at first widely adopted and prized – proved too elementary and was gradually substituted for more complex ones, taking into account the active role of the participants in communication processes, both in giving the message its "real" meaning and in shaping the relationship between communicators.

Research trends and focuses are also related to the developments in media technologies, characterized by rapid and outstanding changes that are reflected also upon audience's consistency, composition, and type of exposure.

The power of the mass media remains a relevant issue throughout the tradition of communication research. However, most recent theoretical and empirical studies no longer deal with short-term persuasion effects and no longer consider individuals as isolated members of a mass society. They rather concentrate on long-term effects and on ways in which the media succeed in constructing the image of social reality (Wolf, 1985, p. 137).

They also pay attention to differences among the media and are aware of the relevance of interpersonal networks in "filtering" media messages. The central issue does not pertain to persuasion, but rather to agenda setting. In other words, the media define the topics and the issues about which people will think and will develop opinions, attitudes, and beliefs, providing not just news and information, but also interpretive frames (Noelle-Neumann, 1973).

Of course people did have the possibility of either accepting or rejecting the information provided to them regarding the Chernobyl accident. However, every single piece of it was acknowledged as "truth" within the symbolic reality defined by media communication, with little or no possibility of access to other levels of reality which, so to say, did not exist.

The status of every piece of information – objective data versus probability estimates, hypotheses versus value judgments, etc. – was attributed to all, and each one was placed within the same reference frame. Interpersonal communication networks were triggered by and fed with messages issued by the media. Rumors could only develop starting from such messages.

Our point is that a message actually issued may or may not be received, may or may not be believed, accepted, trusted, etc. To the opposite, a piece of information that is *not* communicated (because it is not available at the time, because it is only derived from sources not within the reach of the public, or for whatever other reasons) simply does not exist; it is not information, no matter how "real" its content may be. Information is not an abstract entity; it becomes real, it takes shape, when it enters a communication system.

6.3 Investigating Perception

6.3.1 Data and sources

From what kind of sources can we obtain information about the perception of the Chernobyl event? Which data are relevant and which are available? What is the empirical basis we rely upon to draw our picture and to attempt an interpretation? How do we test or "measure" perception? What particular aspects of perception are of interest to us?

Answering the last question first, it is not our aim (as should be clear from our premises), nor would it be attainable on a large-scale basis, to deal with perception in terms of an individual's internal representations, i.e., in terms of the ways one pictured the Chernobyl event to oneself, the things one said to oneself, the feelings one experienced.

From such internal experiences, however, elaborated on the basis of personal and social codes and maps, spring the perceptions that are the focus of our interest, and that we treat largely as a set of beliefs on quite a number of issues – in their turn giving rise to attitudes, behaviors, and actions. Our interest is directed to social, rather than individual, phenomena; our frame of reference is of a socio-psychological type.

Even if dealt with in social terms, however, perception – as any other activity of the human mind, as any kind of value, attitude, belief, etc. – is something we can only infer from behavior. We cannot get inside an individual's heads and watch what happens, how thoughts are shaped.

We can observe external behavior and from it infer one's internal mental status; we can also question people about their internal status, about their thoughts, opinions, feelings, perceptions, etc. Even in this case, however, the response we get is a kind of behavior – a behavior of a verbal (and possibly even of an analogical) type – elicited by a verbal stimulus.

We believe that social scientists could greatly improve their understanding of an individual's internal experiences and external behavior, and of group dynamics as well, by developing the ability to detect both linguistic and analogical cues from which to infer and predict structures and patterns. Such talents, however, entail the direct observation of individual and group behavior and, therefore, are of no interest here. Indeed, in our analysis of the social perception of the Chernobyl event, we are trapped in a kind of "mediological cage."

6.3.2 Media accounts as objects of social inquiry

To reconstruct, after several years, the social perceptions related to the Chernobyl accident, social scientists are also paradoxically forced to rely mainly upon media accounts. The reasons for this are not only of a technical and economic kind, i.e., they are not only related to the necessity of collecting data about an extensive geographic area, many people, and a great variety of social groups. The use of media sources is a compulsory choice also for reasons of content. Since we are investigating perception, we have to rely upon the sources that mainly contributed to both shaping perception and accounting for it, i.e., the mass media.

Whether the communications that constituted the basis for perception had a "real" content or not – tested upon criteria other than the one of being experienced through communication – is simply irrelevant here. This means that it is irrelevant relative to the issue of perception formation, *not* irrelevant in an absolute way. For example, the media reported a sudden increase in the number of abortions sought in Austria and Italy (Otway, Chapter 7). We are able to say *now* that statistics do not support such a fact in either country. In particular, with regard to Italy, data on abortion rates were not available to anyone, not even to health authorities, at the time of the Chernobyl accident. They were collected much later and made public only in September 1987 (Senato della Repubblica, 1987). Data for 1986 show a decrease in abortions (at least those carried out within the state health system) compared with 1985 data – both in absolute rates and in rates calculated with respect to livebirths and to numbers of women in a fertile age span – thus confirming a trend initiated in 1983.

What is relevant to our argument, however, is *not* the discrepancy between information derived from media and statistical sources, it is rather their *incomparability.* The media did not report false news. They actually reported information provided by one or several reliable sources. The fact is that precise, objective data were not available at the time of the event, not even to reliable sources.

Without questioning the good faith of the media, we are simply stating that, when issued, the information about increased abortion rates was based upon impressionistic evaluations or very limited samples or both – not representative, and likely not even casual. We are facile prophets if we predict that the statement "the media reported increase in abortion rates" (correctly identified as such by Otway in Chapter 7) is, or will become, for most people including many scholars and scientists "increase in abortion rates" *tout court.*

6.3.3 An example

This is true for many other "facts" and behaviors that were reported by the media. A recent study based upon statistical sources was conducted in Friuli-Venezia Giulia (a region in northeastern Italy) within a project devoted to suggesting measures for implementing a regional policy of civil protection (Pelanda, 1988). The study had to contend with serious and sometimes unsolvable methodological and technical problems in designing reliable indicators of significant behavioral changes within the resident population in connection with the Chernobyl accident and, once designed, in fulfilling the steps required by their operational definition.

For instance, the media and even a well-known Italian research institute (Censis, 1986) claimed that during the period of fallout deposition people stayed home (without, however, providing any empirical evidence to support that claim). An attempt was made to verify whether such phenomenon had actually occurred in the region under study. Having accomplished a first selection of indicators that, in theory, seemed appropriate and measurable – such as absences from school and work, decreased sale of public transport tickets, and increased private consumption of water and electric energy – outstanding difficulties arose when an attempt was made to collect the actual information. Data were often unavailable owing to a variety of reasons: the lack of collaboration on the part of some competent sources, aggregation different from that of the researchers (e.g., different geographic and temporal units), delays in elaborating and issuing data, etc. (Ferrauto, 1988).

As a consequence, the hypothesis of self-confinement could be neither proved nor disproved by "objective" data. It may, of course, be maintained with the status of a hypothesis, or it may also be acknowledged with the status of "truth" at a communication level. At such a level, truth refers not to content, but to existence; i.e., the content of the information was not necessarily true, but – for the very fact of being communicated – information about self-confinement became a "true" experience and entered the processes of perception formation for large masses of people.

However, this communication level must not be confused with the one of actual behavior. We simply cannot say – on the basis of the information available to us – whether self-confinement was or was not a behavior enacted by large masses of people in Friuli-Venezia Giulia or in Italy or in the rest of Europe.

Diverse data about the Chernobyl accident are, at present, available and can be derived from sources other than the mass media. Nowadays, more easily than at the time of the event, we can rely on "objective" data, for instance, on contamination of crops (see Gray, Chapter 4), on health effects (see Sztanyik, Chapter 3), etc.; we can also rely upon data from opinion surveys and upon data and information derived from researches or experiences or both in some restricted areas, etc. However, such data pertain to levels of reality different from the one addressed here, largely dominated by the media: levels which at the time of the accident were, and partially still are, only accessible to restricted groups.

6.4 The Perception of Chernobyl as a "Social Accident"

6.4.1 Issues to the fore

In our opinion, the Chernobyl emergency – as it was reported to the public by the media – has focused the attention of the public on three main issues related to nuclear energy and, more generally, to modern technologies: (1) who decides; (2) what are the criteria for the decisions; and (3) how reliable are decision makers.

After Chernobyl, Europe was divided into two main sectors, separated by East–West political border. When Swedish technicians monitored the increase in radioactivity in their country, they warned all European governments who immediately tried to get information from the USSR.

Each government, however, had to face a complex set of problems: Was the public to be warned? Were preventive measures to be taken to reduce risk of radiation exposure? What social consequences would be entailed in the warning? Would people panic? How would ecological movements, Green parties, and other political forces react to the nuclear accident? And more important, what levels of radioactivity should to be considered dangerous and in relation to which aspects of individual and social life? What measures had to be recommended to or imposed upon people? How much social consensus would the adopted measures encounter?

It seems to us that three main phases can be singled out by the reaction to the Chernobyl emergency, characterized by different definitions of the situation and by different actors involved in decision-making processes. The three phases can be identified, we believe, in all European countries, although with some inconsistencies and lags in relation to chronological time.

6.4.2 Decision makers' perception of the social threat

In the first phase, all national governments in Europe managed the problem by minimizing the significance of the amount of radiation in Europe, though the situation was unclear and was rapidly developing. Official statements reported in the international press paid great attention to the accident in the USSR, reassuring people that there was no risk to human health in Western Europe. So authorities turned the interests and the attention of the public toward the Ukrainian population. At the same time, to reassure people, a "technical thesis" was developed about the difference between "here" (Western Europe) and "there" (USSR): that a similar accident is impossible "here" because of much safer and more modern nuclear technology (Cappelli, 1987; Flavin, 1987; Guizzardi, 1987).

This tactical decision was supported by the fact that during the sociopolitical conflicts of the crisis management, the governments felt threatened not only by possible contamination, but by social and political opposition to national nuclear energy plans. In short, they feared that the nightmare of a nuclear accident may become reality and might lead people to perceive nuclear energy as unacceptable, thus triggering a strong reaction from Green movements and other political forces.

Therefore, the problem of making decisions on well-grounded scientific criteria was only one component of the decision-making process. Moreover, the different evaluations and the uncertainties shown within the scientific community did not give the decisional subjects great support for a "correct" decision. But this was not the main problem in the first phase, since the decision-making process was rather attentive to the urgency of political, economic, and social necessities.

This situation broke down when, borne by the winds, the radioactive pollution began to affect Western Europe. What appeared from media reports was that, rather than coordinating and deciding preventive measures to protect populations from risk pollution, national governments were more keen on criticizing Soviet management of the crisis.

Besides the "technical thesis," the statements of different governments reported in the international press implied that the accident had happened because in the USSR there is no free and democratic debate about technology, economy, and the environment. The problem was therefore stated in terms of the "right" model of society, i.e., of those inner societal conditions which make accurate technical planning possible.

6.4.3 Emergent actors in the decision process

The second phase is characterized by the attempt to redefine the situation to face the problems of radioactive pollution in Europe and to take adequate preventive measures. Two main factors characterized the international, national, and local decision-making processes: (1) the absence of a common definition of risk and (2) the emergence of conflicting actors.

The first factor relates to the disagreement among scientists, whose quarrels about what and how much was dangerous – diffused by the mass media – contributed to the ambiguity and uncertainty in the public. Occasionally, data about radiation exposure displayed by different scientists were inconsistent. More often, data were the same, but diverging evaluations of the effects on the public were made by scientists.

At both the international and the national levels, the organizations involved demonstrated that they were not prepared to monitor nuclear contamination or to manage the emergency. For instance, the World Health Organization was totally absent during the fallout period, and unable to define a common set of preventive measures and recommendations (cf. Linnerooth-Bayer, Chapter 5).

Some political authorities tried to minimize the pollution problems; some did not communicate the data referring to radioactivity or released only partial information. The French decision to maintain silence about the danger of radiation for about two weeks is an extreme case. However, governments in other countries displayed radiation data in a way that seemed to be aimed at minimizing the problem. For instance, early in the emergency, the Italian national organization of civil protection claimed that the levels of radioactivity were not dangerous. Later, when political and social forces started asking for specific data, the Ministry of Civil Protection declared that data about many areas, especially the ones most exposed to pollution, were not and had never been available (Chernobyl Cronologia, 1987).

The second factor that characterized the crisis management was the emergence in the decision field of different actors (social, economic, and political) who tried to defend their interests and influence the decisions of crisis management. By now, it is widely recognized by sociopolitical scientist that the direct and indirect participation of different actors in the decision field is normal in political decision making. However, the way this process works in mass emergencies and in cases of uncertainty and urgency is not yet well understood.

What is clear from the Chernobyl emergency is that institutional authorities, though with slight differences in each country, made their decisions without taking into account the needs of various actors potentially present in the decisional field, and underestimating the problem of social and political "active consensus."

The development of the decision-making process during the Chernobyl emergency in Friuli-Venezia Giulia (Italy) has been the focus of recent research. Two main issues emerged: (1) the uncertainty under which decision making took place relates not only to scientific and technical issues, but also and even more to sociopolitical ones, and (2) despite the urgency the decision makers could not neglect the problem of social consensus or the presence of different actors (social, political, and economic) who, in a democratic society, intervene and participate in the decision field (for a closer analysis, see Tessarin, 1988; Lizzi, 1988).

Decision making is a process that defines and organizes reality. Mostly during emergencies it is aimed at resolving the uncertainty and ordering criteria for the actions of many different actors in the social field. But, to fulfill such a task, the decision must be widely accepted and actively supported by the actors.

Since the authorities, in the second phase of the emergency, did not elicit political and social consensus, a conflict broke out in the third phase. In short, after the institutional authorities' attempt at minimizing the "risk," the different perceptions and evaluations of other social actors were evident through direct and indirect participation in the social organization of the emergency.

6.4.4 The conflict and the "credibility of institutions"

The third phase is characterized by a high level of conflict, where the credibility of the institution is questioned (cf. Poumadère, Chapter 8), and a strong request emerges, not only for a more democratic management of emergencies, but also for enhancing sociopolitical debate before decisions on energy sources are taken. The contrasting interpretations of the situation – displayed by different actors and reflected by the mass media – led to remarkable consequences in both crisis management and public opinions.

Faced with such complex circumstances, not only decision makers showed great difficulty in evaluating and perceiving all the implications of their own decisions, but also lay people became bewildered by the confusion. They could not see radioactivity, but they saw the impact of this threat on society: authorities, politicians, businessmen, experts, scientists, professionals, institutions, all distrusting and opposing each other. In particular, border communities saw the frontiers become quite concrete by virtue of different warnings and different emergency plans carried out even though the physical event was the same. No common criterion was given to people for evaluating the situation and taking preventive measures; thus, the uncertainty was amplified.

Though authorities were afraid of mass panic and justified their decisions as also intending to avoid it, short-term responses to the emergency did not show extensive "pathologies" in the collective behavior. Occasional manifestations of stress and anxiety are likely to have occurred, and some were reported by the media – for example, in Greece (see Otway, Chapter 7) – but mass panic was not the response, nor were extended forms of antisocial behavior.

According to most of the sociological literature – which, however, is based mainly upon studies of natural disasters – individuals tend to react and respond to threats in a rather "rational" (or at least "meaningful") way. They explore and use all possible resources and strategies for escape, and seldom panic (for an excursus of human behavior in disasters see Drabek, 1986).

Usually, in the beginning, people faced with a hazard or an emergency tend to minimize the threat; at the same time, however, they tend to act in a "rational" way, starting to collect additional information to define the situation. During the Chernobyl emergency, people were faced with several sources of information, conflicting messages, different attitudes of sociopolitical groups, institutional authorities, experts, technicians, etc. Thus, it was extremely difficult to obtain a "warning confirmation" and to select an appropriate pattern of behavior to minimize danger.

Social perception of nuclear risk after Chernobyl has rebounded on social institutions, decreasing their credibility. As indicated by a survey on the attitudes of local planners about nuclear power carried out in Italy one year after Chernobyl (Strassoldo and del Zotto, 1988), the common concern is that "nuclear energy itself may be acceptable; what is unacceptable, at the present, is its management in this country."

So the thesis that in the USSR the accident was possible because of the "wrong" model of society where no democratic and free debate could develop around technology, environment, etc., backfired on authorities in Western Europe, directing the public's attention to the ways in which these societies manage goods and values such as human health, environment, and, ultimately, democracy.

6.5 Conclusion

The Chernobyl accident was extensively covered by the media all over Europe and became an everyday experience – although a secondhand experience – for many people. Thus, they were forced to reflect upon the issue of nuclear risk that, very likely, had been alien to many of them up to that time. We are convinced that the topic of nuclear risk appeared to the public as multifaceted.

The experience of Chernobyl was, thus, one of many experiences that contributed to shaping individual and social beliefs, opinions, and attitudes about many issues. We maintain that such issues pertain to technology management, policymaking, and the overall functioning of Western democracies. In summary, our thesis is that the features of the Chernobyl emergency that mainly attracted social perception were not of a technical, but rather of a sociopolitical nature. It appears – on the basis of public demonstrations all over Europe following Chernobyl – that the public was concerned not so much with the problem of radioactivity itself, but rather with the sociopolitical decisions concerning modern technologies, crisis management, energy choices: issues concerning the reliability of institutions and faith in democracy.

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Chapter 7

The Media and Crisis Management

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Ispra, Italy

Modern governments can effectively communicate with citizens only through the mass media, especially in emergencies when people must be informed immediately of developments and advised on what to do. According to an opinion poll reported by Schneider (1986), 80% of respondents got their information about health countermeasures after Chernobyl from the media, while only 3% contacted public health authorities directly.

We investigated how the media in seven European countries communicated information that was technical (dealing with nuclear technology), sensitive (regarding the effects of radiation on public health), and complicated (involving a strong East–West political dimension). Our intent was to identify common problems and to suggest ways in which communications and crisis management might be improved. We have carefully avoided second-guessing specific decisions for two reasons: first, even under similar circumstances quite different policy choices can be equally reasonable and, second, it is impossible to judge decisions fairly without intimate knowledge of the political context and constraints surrounding them.

The countries studied (Austria, Denmark, France, the Federal Republic of Germany, Greece, Italy, and the United Kingdom) are heterogeneous in industrial development and in the status of their domestic nuclear energy programs. Our main sources were the more "authoritative" national newspapers. These were supplemented by weekly and monthly magazines, television broadcasts,

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official statements, and interviews with journalists and public officials. A daily press summary was made of each country with emphasis on the timing and basis of countermeasures, how they were announced, and the general public's response. The summaries (Otway *et al.*, 1986) are too long to be included here, but a list of print sources used is included in the Appendix to this chapter (see also Borelli *et al.*, 1987; Chausse, 1987; Peters *et al.*, 1987).

The print media may not be the most important source of information, but they are more specific and detailed than other media and are readily available for analysis. Checks between television and print media showed that coverage was similar, as were the communications problems. National media styles vary, and reporting of public responses does itself influence public behavior; however, it seems unlikely that these would have an appreciable effect on the conclusions.

7.1 Communication Needs and Government Responses

Upon becoming aware that an accident had occurred, governments were confronted with the necessity of managing an emergency whose dimensions were yet unknown, and of meeting public demands for information about it. In general, governments were not well prepared to do this for several reasons: they did not immediately know the nature of the accident, so they did not know what consequences to expect or when to expect them; their monitoring systems were not suited to widespread and nonuniform radioactivity originating outside the country; and they did not always have pre-established intervention levels or countermeasures.

7.1.1 Early information about the accident

The first indication of the accident in Western Europe was the detection of airborne radioactivity in Sweden two days after its start. Meteorologists forecasted that the radioactive cloud would stay in Northern Europe for some time and might even be harmless when it reached Central and Southern Europe. Little information was available about the accident or the extent of the release. However, the release of radioactivity continued and weather conditions changed, bringing the cloud south. Many governments were not prepared for the speed with which the cloud arrived or the high levels of contamination it caused.

Authorities responsible for the management of radiation emergencies had generally not anticipated that a reactor accident could result in such high levels of contamination so far from the plant. A reactor accident is commonly conceived as causing a sector of contamination downwind from the site, decreasing in intensity with distance, with significant downwind contamination limited to some tens of kilometers. But the Chernobyl release went much higher than usually assumed in accident calculations; the cloud encountered different wind conditions as it rose, and fallout patterns were affected by local rains. Consequently, contamination levels bore no simple relationship to distance from the reactor. For this reason, early calculations made in the West overestimated the size of the release and the number of casualties close to the plant.

7.1.2 The source term controversy

Contamination of an entire country, caused by an accident so far away, had not been expected, so monitoring systems tended to be focused on nearby nuclear facilities and were ill-suited to monitor widespread and uneven contamination. Early reports by Western officials criticized the Soviet Union for not providing more information on the accident's sequence of events, the extent of damage, and the amount and type of radioactivity released. It was widely claimed that the lack of information was hindering crisis management.

The Soviet government did not admit that an accident had happened for about 64 hours. Although this was a problem for Denmark, Finland, Poland, and Sweden – countries that learned about the accident through their own routine atmospheric monitoring programs – many early problems encountered by crisis managers were not really due to uncertainty about the source term but, rather, due to the insufficient amount of good information about what was happening in their own countries, i.e., the cloud trajectory and local radiation measurements.

Local information could hardly have been provided by the Soviet Union, and, in view of their organizational problems and the technical uncertainties, it seems doubtful that Soviet authorities in Moscow even had reliable detailed information (Gubarev and Odinets, 1988). It might also be recalled that similar organizational problems were seen after the Three Mile Island (TMI) accident in the USA when it was only some days after the accident that reliable technical information was available. At TMI, the optimistic mind-set of the private utility operator and a general desire to protect the nuclear industry seriously damaged the credibility of early information released. The first press releases were unjustifiably soothing, not to mention deceptive (Rubin, 1987).

There was some sensationalist reporting in the West of early events in the Soviet Union, but some of this was a faithful repetition of information from apparently credible sources. For example, in the first days after the accident the media widely reported thousands of deaths in the vicinity of the reactor (15,000 bodies buried in a mass grave), riots in Kiev, and an out-of-control fire in a second unit. Most of these stories originated in the US media and were attributed to US "intelligence" sources in the European media, leading Secretary Gorbachev to refer to "malicious mountains of lies." As it turned out, official Soviet information later proved correct (see Walker, 1986, for a journalist's account of reporting the emergency from Moscow and the origins of some of the more bizarre news stories).

7.1.3 Actions required of government

Many governments had to formulate strategies to respond to the crisis as it was developing, e.g., monitoring radioactivity, setting tolerance levels, and recommending ways to reduce exposure. Atmospheric radioactivity as well as surface concentrations and levels in both imported and locally produced foodstuffs had to be monitored.

Tolerance levels were sometimes available for other contingencies, but ad hoc arrangements had to be made to locate and deploy the necessary equipment and manpower for this particular application. In other cases, where tolerance levels had not already been decided upon, they had to be determined rapidly, often without time to consider the many theoretical and practical questions involved. Ways devised to limit radiation exposures included banning certain foodstuffs from the market, setting consumption limits on others, and recommending personal behaviors that would minimize individual exposures, e.g., by not drinking rainwater and by not letting children play outdoors.

There were immediate demands for information on environmental radioactivity, its level in various foodstuffs, the corresponding health implications, expected future developments, and ways that individuals could limit their exposures.

7.2 Common Communications Problems

Several problems related to communications were encountered, in varying degrees, in many of the countries studied. Those discussed below were the most common.

7.2.1 Organizational confusion

Government responses required action by several departments and ministries. Because the goals and responsibilities of each organization are different, the result was often friction and confusion. In particular, there seemed to be conflicts between economic interests and public safety in decisions to ban agricultural produce. Agriculture ministries, or local authorities in rural areas, tended to support higher intervention levels than those recommended by public health officials.

There were also conflicts between members of government and senior civil servants. Webster (1986) reports that a senior spokesman of a health agency tried to give reassurance by saying that "a few tens of people" would die because of the late effects of Chernobyl, but the responsible minister, either thinking only of immediate health effects or ignorant of long-term effects, announced that there were no health risks.

7.2.2 Anticipating the need for countermeasures

Besides inadequacies in local monitoring, there was little attempt to use whatever local information was available in conjunction with models of atmospheric transport and radioactivity deposition and uptake by humans and animals to foresee crisis management needs. For example, the first countermeasures focused on the threat posed by I-131, which was initially the greatest contributor to radiation exposures. In several countries, shortly after restrictions on iodine contamination were lifted, it was necessary to re-implement them because of cesium contamination. This created confusion about which countermeasures were actually in force and hurt public confidence in the management of the crisis.

In the case of the sheep farmers studied by Wynne *et al.* (1988), the failure to anticipate foreseeable events caused serious financial losses. Farmers were told that contamination would last only a few weeks and that restrictions would be lifted before their lambs went to market. However, the crisis lasted much longer, and compensation claims were often rejected because of incomplete documentation – documentation that the farmers had not collected because earlier the same ministry had assured them that they need not worry because there would be no significant losses.

7.2.3 Explaining countermeasures

Many different intervention levels exist for particular foodstuffs, used by different countries and international organizations, and it was often unclear which levels were actually being used. Furthermore, well-intentioned people sometimes behaved inappropriately when following government advice without understanding the reasons for it, e.g., by consuming long-life milk packaged after it had already been contaminated or by bringing a contaminated sandbox into the house after instructions had been given not to let children play outdoors.

There was confusion about the extent to which the implementation of countermeasures was the responsibility of the government or of the individual, informed by government advice. For example, sometimes people were advised not to consume more than a certain amount of some foods while other foods were withdrawn from the market. Thus, consumers were unsure if foods available in shops were free of radioactivity or not.

Sometimes countermeasures failed to distinguish between produce grown in the open and similar, but uncontaminated, produce grown in greenhouses (e.g., lettuce and strawberries). The consumers' inability to check personally for radioactivity, coupled with suspicions of the shopkeepers' knowledge of where products originated, and an awareness of conflicting government objectives caused apprehension to buy any fresh produce at all. Another complication was that it was relatively easy to tell when countermeasures were instituted, but difficult to know when they were removed, perhaps because the imposition of countermeasures is more newsworthy (see Peltu, 1985, for a discussion of how the media determine what is "news").

Perhaps even more serious was the fact that countermeasures sometimes failed to appreciate the realities of the lives of the individuals who were expected to act on them. Taking again Wynne's (1988) example of sheep farmers, advice to hold the new lamb crop on the farms until radioactivity decayed simply neglected the realities of balancing the availability of grass, the condition of the sheep, parasite buildup, market prices, the availability of help, and the need for capital. Worse, advice was given to feed straw to sheep, leading one farmer to say: "I've never heard of a sheep that would look at straw as fodder."

In summary, official advice was sometimes unrealistic and, in the deed, impossible to implement. However well meaning advice may be, the loss of credibility caused by inadequate or confusing recommendations spills over into other issues, is likely to erode the credibility of other authorities, and is extremely difficult to repair.

7.2.4 Radiation units

In all countries there was a serious problem of reporting quantitative information, especially with regard to radiation measurement units. Contamination levels were reported in röntgen, curies, or becquerel per kilogram, liter, square meter, etc. Radiation exposures or doses were given in rads per unit time or in grays, while dose equivalents were given in rads or sieverts. Milli-, micro-, pico-, and nano-units of the above were also used, sometimes as if the basic units with different prefixes were completely unrelated. The time rates used also varied widely, e.g., per second, per hour, per day, or even over a lifetime.

Confusion was caused first by different units being used, sometimes in the same report, without providing information on how to convert them and second because units were used incorrectly, making the information meaningless even to specialists (e.g., by not indicating the time unit of a rate measurement). This was not only a media problem; often ministries within a country used different units, and the press simply reported the information given to them. In some cases, the media were careless because they did not understand the importance of prefixes or the time dimension.

7.2.5 Relating exposures to health effects

Raw numbers on radiation exposures mean little to nonspecialists because these measures are difficult to relate to health effects. Attempts were made to put these numbers into context by expressing them as fractions of allowable limits, but the limits were rarely explained, i.e., to what situations they apply or how they relate to health effects. Also, various limit values were used, often inappropriately or without proper identification, e.g., the ICRP recommended yearly occupational whole body dose equivalent, the public dose limit, the dose required for the onset of acute effects, or the dose at which half of those exposed would die of acute radiation sickness (the LD-50).

Exposures to Chernobyl radiation were also compared to familiar activities that involve exposure to natural radiation: e.g., vacationing in the mountains, traveling by air, or moving to a part of the country with higher background radiation. These comparisons were generally regarded suspiciously by the press. One reason may be that comparisons of industrial accident risks to leisure time activities seem obviously inappropriate; another explanation is that they have so frequently been used by nuclear experts to put prospective accident risks "in perspective" that they are now simply discounted as being part of self-serving promotional campaigns.

Alternatively, the cancer deaths expected from Chernobyl were compared to the large number of "natural" cancer deaths. The intent was to demonstrate the relative insignificance of radiation hazards, but its success as a communications strategy requires that the public accept this as a legitimate comparison. This seemed not to be the case, partly because up to 10,000 additional cancer deaths were predicted for Europe.

7.2.6 Differences across national borders

Several different intervention levels were used by the countries studied for the same foodstuffs; in the Federal Republic of Germany, there were also differences among the state (Länder) governments. Countermeasures based on political judgment were also not consistent – especially noticeable in the official responses to similar levels of contamination across political boundaries. For example, in the West German city of Wiesbaden the mayor closed public parks and swimming pools, while in Mainz – just over the Rhine – they remained open. Similarly, the Federal Republic of Germany placed restrictions on vegetables and milk, while across the Rhine, in France, there were none. In Austria, parents were advised to keep children indoors, while in Italy they were not.

On the Swiss–Italian border, differences in the averaging and aggregation of data caused apparent inconsistencies in the reporting of radioactivity levels. Italy, a peninsula with north–south cultural differences, reported aggregated levels for northern, central, and southern regions. However, the Swiss, with cultural differences across language groups, aggregated in terms of linguistic region. Thus, in the Italian-speaking Ticino region of Switzerland, which experienced heavy rains, radiation levels were reported that were about 10 times higher than those given in the Italian media for northern Italy. The part of Italy bordering on Ticino, which experienced roughly the same contamination levels, was averaged with drier parts of the north. Both sets of data were correct within their own terms of reference, but the apparent differences were confusing to those who followed the media of both countries.

7.2.7 Unusual public reactions

The entire range of public responses cannot be documented from media reports because unexceptional behavior is not newsworthy; Schneider (1986) estimated that 60% of the public complied with government recommendations, making radical changes in their life-styles to minimize risk.

Nevertheless, some extreme responses were reported: a sudden increase in the number of abortions sought (in Austria and Italy); panic buying of long-life foods in most countries, but reaching near-riot proportions in Greece; buying radiation-measuring equipment for personal use (United Kingdom and the Federal Republic of Germany); an increase in antinuclear demonstrations, including demonstrations at nuclear sites in bordering countries (e.g., groups demonstrated in Bavaria and in Prague and Budapest, where individuals were arrested); deaths and hospitalizations due to self-administered overdoses of potassium iodide in the Federal Republic of Germany (this stable iodine compound blocks the thyroid gland so it cannot take up radioactive iodine – pharmacies in Denmark reportedly sold out of it shortly after the accident); suicides attributed to anxiety or economic losses caused by Chernobyl.

7.2.8 Changes in public opinion about nuclear energy

Post-Chernobyl public opinion polls posed questions for governments committed to nuclear energy. Each poll was phrased differently, but opposition to nuclear power was invariably seen to have increased. In 1982, 52% of West German respondents supported nuclear energy, with 46% opposed; after

Chernobyl the figures were 29% and 69%, respectively. A UK Gallup Poll in March 1986 showed 34% supported increasing nuclear power generation and 53% against; results in May were 18% and 75%, respectively.

Polls also suggested dissatisfaction with government information. In a 1986 Harris Poll, in France, 13% agreed that "they are telling the truth about Chernobyl" while 74% believed that "they are not telling everything." Hohenemser and Renn (1988) have summarized pre- and post-Chernobyl changes in public opinions about nuclear energy in 11 European countries.

7.2.9 Special information telephones

Many countries set up special telephone numbers where people could get additional information or check rumors. Often demands for information were so heavy that the lines were overloaded and callers could not get through. (In one country, incorrect numbers were mistakenly published.) Even worse, when they did reach someone, callers found that those who answered were overworked and abrupt or able only to give general reassurance and repeat information already available in the media.

People with very specific and (to them) important questions, such as farmers who needed to know if grass could be fed to livestock, were unable to get detailed information. Overloaded special telephone lines sometimes caused people to call authorities at their normal telephone numbers, jamming switchboards and making crisis management even more difficult.

7.3 Discussion and Conclusions

7.3.1 Organizational aspects

The widespread impression was that governments were not well prepared for the crisis management problems presented by Chernobyl, partly because of its international dimension – a fairly recent phenomenon in industrial accidents. It was often apparent that strategies were being improvised, evidenced by frequent reversals of decisions and by the different policies chosen by different countries to solve the same problems. This was complicated by conflicting information provided by different government departments or even by various hierarchical levels within the same department. Also, the desire for information responsive to the needs of specific groups was underestimated, causing delay in the provision of information, inadequate information, and a consequent loss of credibility in crisis management.

Paradoxically, even if crisis management organizations and procedures are set up in advance, there are inherent problems of maintaining readiness. Every crisis is different; plans made in advance will still need to be improvised as the nature of the particular crisis becomes apparent. In addition, plans existing on paper need frequent updating and must also be rehearsed often. Experience has shown that the problems of updating information and maintaining proficiency are serious ones; day-to-day responsibilities inevitably take precedence over special assignments to emergency teams. It is also expensive to assign people only to emergency tasks, and boredom caused by long periods of inactivity also causes problems in maintaining proficiency.

Personal goals may conflict with intentions to limit official sources of information. Elected politicians may still want to be seen by the media and the public to be actively involved in crisis management. Government changes occur more frequently than major crises, thus politicians may not have first-hand experience of previous crises, increasing the possibility of repeating past mistakes.

7.3.2 Risk communication: Macro-risk versus micro-risk

Public confidence was not helped by overly technocratic efforts to put Chernobyl risks "in perspective" by comparisons with natural death rates or the risks of dissimilar activities. This was viewed as an attempt to minimize or to cover up the accident's consequences. The regulatory role deals with "macro-risks," the threat to the health of society. The individual, however, asks the "micro-risk" question: "What does this risk mean to me and my family?" Successful communications require those in authority to be sensitive to this distinction and to address both issues (Sharlin, 1986).

In the case of Chernobyl, attempts to provide reassurance using comparisons that blurred the macro–micro risk dichotomy often backfired; 50 additional cancer deaths may not seem like much to public health experts who frequently think in terms of hundreds of thousands of "natural" cancer deaths each year, but an increase of 50 deaths, visualized by lay people as bodies to be put in coffins and buried, is a considerable amount – especially when caused by a reactor no one had ever heard of, in a distant and unfamiliar land.

People were concerned to hear their own public health authorities essentially say that it did not matter because so many people die of cancer anyway. Carrying this logic to the extreme implies that an equal number of deaths could be caused by every industrial facility in the world and still not matter – a position that most people would intuitively reject.

Often the spokesperson who said that the additional cancer deaths were insignificant also said that technologists could learn nothing from the Chernobyl accident because Western technology is so much more advanced. This made the nuclear experts seem arrogant and damaged the credibility of public health information because it was suspected of being influenced by a desire to protect the domestic nuclear industry, especially where governments officially support nuclear energy.

The majority of the public in most countries regarded government information provisions as inadequate; people seemed to feel that the public health threat was worse than government sources said. But public authorities faced a most sensitive communications problem, the inherently difficult one of credibly transmitting a double message – asking people to change their daily lives to minimize risk while, at the same time, urging them not to become unduly anxious or to overreact in ways that might be equally dangerous.

7.3.3 Media accuracy

We found, in agreement with a study of the UK media (Herbert, 1987), that the more "responsible" print media did a fairly good job of covering the accident, especially in conveying information provided by authorities. The media did have problems with highly technical topics, especially with units of radiation, contamination, and exposure; however, many scientists not working in the area of radiation protection on a daily basis were unaware of the "new" International System of Units (SI) and were forced to consult references (see Appendix to this volume).

The scientific-technical community tends to judge media accuracy by scientific standards. The typical scientific paper takes months to draft and may not appear in print for a year or two. Journalists, in contrast, often have deadlines measured in hours, perhaps even minutes, and the material may appear the next day; thus, some inaccuracy in technical matters is inevitable, and should not come as a surprise. This will always be a problem in the coverage of emergencies; it is unrealistic to expect journalists to be informed of the technical details of all varieties of hazardous facility.

The media will always check government information with unofficial sources such as university laboratories and "independent" scientists, and whatever scientific disagreements exist will be mirrored in this supplementary information. Where consequences are uncertain, and thus open to genuine differences of opinion, these divergent viewpoints will be reported – with implications for the credibility of official information, especially if government credibility is already in question.

The only way that authorities can be perceived as being credible in emergencies is if they have already earned credibility in their daily dealings with the public. The cosmetics of packaging and presenting information cannot cause a previously untrustworthy source suddenly to be perceived as credible.

7.4 Recommendations

This analysis suggests several recommendations to improve emergency management and communications, the first two of which are specific to nuclear accidents.

Standardization of radiation units. The effects of radiation have been more extensively studied than those of any other toxic agent, and there is substantial agreement (at least in official circles) on dose-response relationships, thus it is ironic that so much confusion was caused by misunderstanding of the basic units. This could be improved by ensuring consistency in official circles and by using only SI units. Nongovernmental laboratories should also be encouraged to use standard units since it does not affect their independence. Some confusion is inevitable since measurements made under different conditions cannot readily be compared, e.g., per kilogram of wet and dry grass.

Aggregation rules. Aggregation of contamination data is necessary and is likely to cause disagreements even in the best of circumstances. Aggregating data from areas that have experienced quite different weather conditions, and thus have widely different levels of contamination, must be avoided. Aggregation decisions should also consider factors such as population density and land use, recognizing that individuals are sensitive to maxima as well as average values.

Communications credibility. Communication with the public is central to effective crisis management. Governments have a responsibility to intervene in the marketing of foodstuffs and to provide services required to reduce risks, but the effectiveness of countermeasures in practice depends upon individual decisions. Sensible public behavior can result only from adequate, understandable, and credible information. This has obvious implications for a government's day-to-day dealings with the public.

Organizational aspects. Crisis management procedures were generally perceived by the public as inadequate and confused. This was typified by disagreements, for instance, between ministries. The need for centralized information dissemination became apparent as the accident progressed when journalists had trouble identifying official sources, the public was not sure where to turn for information, there was uncertainty about the impartiality of the information that was available, and there were discrepancies among various official sources. It is important to have, and to present to the public and press, pre-established methods for dealing with crises of this sort. Obviously, every crisis is different, but organizational relationships should be defined in advance to avoid overlapping responsibilities and conflicts of interest in the heat of a developing crisis.

Transboundary harmonization. The harmonization of intervention levels has a strong political dimension because different policies can result from equally reasonable trade-offs among political, economic, and safety considerations. However, the fact that intervention levels vary across national or state borders undermines the credibility of government choices, because the public expects health and safety issues to be the primary consideration.

Information hot lines. Special telephone operators who can give quick and authoritative answers to particular questions can help to show that those responsible are "on top" of the situation and to reduce the spread of rumors. The telephone lines must function properly, not be overloaded, and be staffed by well-informed individuals who are skilled in dealing with lay people who may be somewhat over-anxious. In addition, the numbers should be published accurately. Arrangements for an adequate supply of telephone lines and special training for enough people to staff them should be made in advance so that the emergency information system can be rapidly activated when needed.

"Education" and communication. In view of the wide variety of conceivable emergencies, suggestions that journalists be "educated" in the scientific and technical details of hazardous technologies are unrealistic. They should, however, be helped to understand crisis management procedures as background for dealing with particular emergencies. Governments should prepare information in advance for specific cases, e.g., on radiation units and their meaning. Scientists and public officials who have responsibilities for communicating about risks should learn more about how the media work and what their constraints are. Scientific standards of accuracy should not be expected of journalists, who must work under severe deadline pressures amid confusion that is not of their making.

Scientists and public officials are generally not good at clearly communicating complex information, itself clouded by uncertainty, to journalists and the public. This requires improved communication skills, an understanding of how risks are perceived, and knowledge of how to express technical information so that it is meaningful to nonspecialists.

Some very good guides to successful communications that reflect these principles are starting to appear (e.g., Hance *et al.*, 1988), but we must be sensitive to the fact that this research has an inherent political dimension and a potential for manipulation that may depend less on the content of the research than on the intent with which it is ultimately applied (Otway, 1987).

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Appendix: Print Media Sources

Austria: *Neue Kronen Zeitung, Kurier, Die Presse, Profil, Wochenpresse, Wiener, Wiener Zeitung.*
Denmark: *Information, Weekendavisen*, press releases and summary reports from Miljoestryelsen.
Federal Republic of Germany: *Süddeutsche Zeitung, Die Zeit, Frankfurter Allgemeine Zeitung, Der Spiegel.*
France: *Le Figaro, Le Monde.*
Greece: *Kathimerini, Makedonia.*
Italy: *Il Corriere della Sera, Il Giornale, La Repubblica.*
United Kingdom: *Times, Financial Times, Guardian*, several weeklies.

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Chapter 8

The Credibility Crisis

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8.1 Introduction: Something Worse than the Bad News

Those who said that the twentieth century is the century of the atom didn't know how right they were. Certainly, the scientific discovery of a particularly powerful new energy source had produced hopes and applications in both the civil and military sectors. In the final equation, though, it is the major accident at Chernobyl that dramatically and suddenly brought the reality of the atom's presence home to many persons and groups around the world.

Some see in this accident future perspectives darkening those sketched by the accident at Three Mile Island. Chernobyl is held up to be the confirmation of nuclear power as an unacceptably dangerous technological choice. Others appear to feel that this accident represents one of a long and unending series of human-made disasters that beat the rhythm of our existence: Amoco-Cadiz, Bhopal, Sandoz, collisions of trains, boats, and airplanes, etc. Still others, perhaps the most numerous, seem to awaken out of a routine existence in which they were as if held at a distance, protected from the possibility of a large nuclear accident. The presence of nuclear industry in industrialized countries, the repeated guarantees of high levels of safety offered by governments and experts, the profound wish we all harbor that all goes well in our world had eased our peaceful retreat into slumber and caressing dreams of totally safe nuclear energy.

In Europe, especially, where the high concentration of nuclear power installations is matched by the proximity of national borders, this sudden awakening forced by outside events has produced an overall credibility crisis: the Chernobyl accident is bad news, but the worst is perhaps yet to come.

The special nature of this crisis and its profound workings may be more easily understood with this fictional telephone conversation:

"Hello, my friend, I have the results of your analyses from the health center."

"Thank you for calling. We both know my situation is critical, and I asked you as a friend and medical expert to reveal the truth to me. So go ahead, what do you have to tell me?"

"Well, I'm afraid I have bad news and even worse news. Which do you want first?"

"Tell me the bad news."

"I am so sorry, the results say you have only two days left to live."

"I was afraid of that. But you said you had worse news. What could possibly be worse than that?"

"I tried to call you yesterday."

This somber story illustrates to an extreme degree that there can be something worse than the bad news: some tragic events require us to put things into a fundamentally different perspective. Life will never again be just as it was before.

The bad news of the Chernobyl accident became worse news in different ways for different people, as a function of many variables. One such variable is proximity to the site: the radically revised conditions experienced by those closest to the accident are death for some, high exposure to radiation for others, and the displacement of large populations. Many other persons and groups, as well as the global environment, have been exposed in varying degrees to radiation. It appears that in Europe the effects are, and will remain for some time, difficult to evaluate with precision. Still, it is possible to say that the vast majority of the European population has been exposed to the bad news of the accident, and with it the obligation of coping with the new perspectives imposed by it.

It has already been established how previous human-made disasters, especially those associated with the release of toxic matter, have pathogenic effects, regardless of whether or not the actual physical exposure can be proved to be dangerous to the organism. In the domain of large accidents, research is lacking on the factors and mechanisms which mediate the social and psychological impact these accidents have upon individuals and populations.

This chapter explores those perspectives at several levels. Nuclear accidents resemble in many ways other human-made disasters rooted in technology. At the same time, though, nuclear accidents have specific characteristics that make them a critical social and human experience. Understanding these two levels of dynamics can lead to a better appraisal of the crisis experienced and its possible evolution. Based on this knowledge, better ways of helping victimized populations could be designed.

8.2 The Chernobyl Accident as a Human-made Disaster

Catastrophes have always been part of human existence, at least in the sense that a persons' relationship with the natural environment proves sometimes to be negative. Technology might represent some of the attempts made by man to reduce negative experiences coming from nature and to increase satisfaction by controlling the environment. Unfortunately, natural disasters are far from being under control. Nevertheless, another category of disaster, associated with the development of technology, has appeared: human-made disasters.

Comparisons and contrasts with natural disasters and human-made disasters have been frequently established. In a review of the matter, Baum (1987) has put together a summary table (see *Table 8.1*). The sources for this table include published descriptions and impact evaluations of several human-made disasters, including: the fire at Cocoanut Grove, a Boston nightclub; a collision between two ships; the Buffalo Creek flood in West Virginia; the Three Mile Island accident; and various leaks of toxic chemicals. The Chernobyl accident can be screened through the characteristics identified in this table. Based on available data, it can then be ascertained to what extent the Chernobyl accident is typical of human-made disasters.

Suddenness. Seen from the outside of the nuclear power plant, the Chernobyl accident of 26 April 1986 occurred very suddenly, with no warning signs. From this standpoint, it resembles other human-made disasters such as the collapse of a dam or a bridge. Little precise information is available on the announcement of the Chernobyl accident to the immediate rural communities in the first few hours following radiation release. They had little intimation of the problem and little preparation for the later wholesale evacuation of the population. This suddenness is amplified in that radiation is invisible, immediately permeating, and not entirely comprehended by the general public.

In the international community, knowledge of the accident was all the more sudden in that it came indirectly, through the interpretation of extremely puzzling circumstances. Swedish workers *arriving* at their nuclear plant triggered radiation monitors, confronting decision makers with unexplained data requiring rapid review of a wide range of unanticipated hypotheses. It was

Table 8.1. Characteristics of natural and human-made disasters.

	Disasters	
Characteristics	Natural	Human-made
Suddenness	Often sudden, some warning	May be sudden or drawn out
Impact	Usually powerful	Usually powerful
Visible damage	Usually causes damage, loss	May not cause damage, loss
Predictability	Some predictability	Low predictability
Low point	Clear low point	Unclear low point
Perception of control	Uncontrollable, lack of control	Uncontrollable but potentially controllable; result of loss of control
Extent of effects	Usually limited to victims	Victim's and public's loss of confidence and credibility in perceived human agents
Persistence of effects	Up to a year, mostly acute	May be chronic, long-term uncertainty

(Source: Baum, 1987.)

the Swedish authorities who announced to the world that weather patterns indicated radiation was emanating from a site in the USSR.

Suddenness is not only a technical parameter, but very much a question of perception: Are people prepared to learn that their environment is profoundly and invisibly altered? In all parts of the world, people were astonished by this sudden shift in reality, appearing as a news flash in the media or relayed by word of mouth. As we shall see, it was not only the physical environment that underwent radical change in the minds of the people.

Impact. The health impact of the accident was powerful. The meltdown and burnthrough of the reactor core and violent release of radioactivity killed 31 persons (operators and fire fighters). Although difficult to assess, and thus controversial, it appears that about 300 persons were exposed to extremely severe levels of radiation. Wide-range and long-term health impacts are even harder to quantify. Thyroid tumors from radioactive iodine intake through milk consumption could range from 12,000 to 200,000 cases; through inhalation, between 2,500 and 30,000 cases. Other cancer pathologies, stemming from whole body exposure or from intake of radioactive cesium, could amount to from 4,000 to 60,000 cases. Overall, up to 100,000 persons are thought to have been exposed to levels that will require medical follow-ups for negative health effects.

Another level of impact was that upon public attitudes toward nuclear energy. The belief that a major accident in a nuclear power plant is an insignificantly remote possibility was severely shaken. Public anxiety about radiation has been potentialized. Although difficult to assess, it is likely that pathologies associated with both acute and chronic states of anxiety have arisen.[1]

Visible damage. The Chernobyl accident caused a wide range of physical damage. Several hundred square miles of land surrounding the plant were either barred from all use or necessitated radiation cleanup. In the immediate area, the Soviet authorities had to evacuate and resettle more than 100,000 persons, half of whom were able to return to their homes after one year. The town of Chernobyl has been razed.

In Sweden some 100,000 reindeer were destroyed. Several other European countries were obliged as well to destroy crops and foodstuffs that were irradiated beyond the levels that were considered safe for consumption.

The economic cost is extremely high. Although the cost of a reactor accident is difficult to assess completely, that it is high is evidenced by the fact that experts have agreed that only governments, and not private concerns, could possibly dispose of resources sufficient to reply.

Predictability. This is a particularly controversial issue. Opponents of nuclear energy have regularly sought to keep the possibility of such a disaster in view. The Chernobyl accident is close to being the "worst possible case" projected by some experts. From another perspective, Perrow (1984) concludes that such accidents are "normal," inasmuch as they are produced by the unmanageable complex interaction of technological and human factors in operating systems.

Simon (1983) draws our attention to the human will to be rational, and equally to the difficulties confronted on that path. These stem from such sources as one's reduced short-term memory capacity which puts a ceiling on one's information treatment abilities. These limits induce typical individual behaviors that are far from optimum. Similar typical behaviors appear at the organizational level as organizations are composed of individuals with bounded rationality.

Crozier (1963) has also documented the detrimental impacts on overall organizational effectiveness of intergroup power conflicts and information control. Poumadère and Mays (1988) report on how individual and organizational values can vary throughout the work structure of a nuclear power plant and how these variations can have an impact on overall safety effectiveness.

Unless these issues of complex systems, bounded rationality, and intergroup relations can be effectively addressed, one can argue that human-made disasters in large engineered systems are in some way predictable.

In the precise case of Chernobyl, however, and from the strict point of view of operators, it can be argued that predictability in that context was quite low. This simply because, if any real awareness had existed of the risk present, corrective steps would have been taken much earlier in the sequence of events. Of course, the issue of why such awareness did not exist is probably a result of some extremely complex interaction of the factors mentioned above.

Low point. Certain technological accidents can indeed have a low point, that is, a clearly identifiable moment at which the damaging action ceases and from which time recovery can begin. The low point in the case of Chernobyl, though, is difficult to determine. For instance, those persons who have reason to think they were exposed, directly or indirectly, can still fear long-term effects upon their health that may not be evident until many years have passed. The extent of damage across time then remains uncertain. Numerous events may appear from one moment to another that make up part of that category of things included in "worse than the bad news" of the accident itself.

Perception of control. Natural disasters are often perceived as being outside human control. The assumption, though, that technology as a human production should remain within our mastery leads inquiry to focus upon the very loss of control from which the disaster resulted. Studies of attribution of responsibility draw upon that tendency. Drabek and Quarantelli (1969), for instance, show how decision makers could be held responsible for not having prevented the explosion of a gas tank in fairgrounds.

Top managers at the Chernobyl plant have been severely criticized and blamed for the accident by Soviet state officials. Such scapegoating processes, which amount to blaming the victims, were expressed in other countries by criticizing deficient Soviet nuclear technology. One effect of such scapegoating is that it can lead those who differentiate themselves by this means to believe or make believe that they are not concerned with the occurrence of such an accident at home. "It can't happen here" was often stated shortly after the accident. Since the time of that immediate attempt to push away the undesirable reality of the accident, lucid reflection has led most experts to admit that they cannot be so categorical about the probabilities of reexperiencing a large accident of this sort.

Extent of effects. One effect of a human-made disaster is loss of confidence and credibility in those perceived to be the human agents involved in the accident. This attitude change is not limited to immediate victims, but affects in deep ways the general public as well. In the case of the Chernobyl accident, we can see how this is particularly true. Beyond the fact that many persons probably consider themselves to be victims of direct or indirect radiation exposure, more "victims" might exist among those suffering from the effects of the ruptures suddenly caused by the Chernobyl accident. Otway (1987) warned that the effects of Chernobyl should not be underestimated in the sense that they might change forever the relationship between lay people and experts.

Loss of both confidence and attribution of credibility is apt to be a nonlinear process and, thus, difficult to assess. Several polls have attempted to measure changes in European attitudes toward nuclear energy by comparing opinions before and after the Chernobyl accident. According to Roser (1987), General Secretary of the German Nuclear Forum, differences do exist from one European country to another in terms of the public's expression of hostility toward nuclear energy. He concludes in part by stating that "public opinion on nuclear energy in Europe is slowly regaining its pre-Chernobyl position" after measured worsening.

But measurement and comprehensive evaluation of data at that level of public opinion are difficult to perform. There is no ongoing systematic monitoring of public opinion in Europe. Furthermore, such a major event as Chernobyl has a cognitive and affective influence on the perception evaluation of other topics. Thus, the structural dimensions themselves of the referential systems used to represent opinion data become modified (see Ansel *et al.*, 1987).

Persistence of effects. Considering the uncertainty regarding a clearly marked low point in the case of Chernobyl, combined with shaken public confidence in nuclear energy, long-term effects at many levels are likely to maintain themselves. In no part of the world since Chernobyl can nuclear energy be generated just as before. Despite the purported improvement of its image in European polls, nuclear power – as a perfectly safe technology – can no longer be defended rationally. A doubt exists; ultimately credibility of the power source, and those who defend it, has taken a blow.

Though this doubt is now part of every person's reality, the existence of nuclear power plants in high concentration in Europe is equally an undeniable part of reality. One policy response has been to plan phaseouts, but the continuing proximity of functioning plants in geographically close sites is nonetheless inevitable. Nuclear power in Europe cannot be replaced overnight by other sources. The conflict between lowered credibility (composed of rational doubt amplified by irrational response) and the incontrovertible presence of installations is apt to be a chronic stressor to large populations in Europe.

The Chernobyl accident fits the descriptive pattern that has been established through the study of other human-made disasters. It is apparent, though, that some of the major characteristics of the accident are specific to its nuclear context. In the next section, I will attempt to analyze the unique deeper impact of the nuclear accident.

8.3 The Uniqueness of Nuclear Disasters

Section 8.2 shows how the Chernobyl accident can be identified as a human-made disaster. Nuclear technology, however, belongs to a category unto itself in that public anxiety over nuclear accidents and radiation hazards appears to be of a *fundamentally different nature* from anxiety associated with other technological accidents and hazards. Physiological aspects of severe exposure to radiation are well documented. The psychological impact, through stress agents linked to the threat (real or imaginary) and which can lead eventually to specific pathologies, is beginning to be studied. This section treats the uniqueness of nuclear accidents in terms of their being a critical life event, triggering specific social and psychological reactions and ways of coping. Special attention is given to basic factors structuring deep responses that build into a credibility crisis.

8.3.1 The rupture of a de facto contract: Nuclear accidents are not supposed to happen

As I have commented earlier, by definition no accident is ever supposed to happen. If individuals are aware of the rising possibility of an accident, then they take steps (whether efficient or inefficient) to stop the process. However, while the idea of accidents in most areas of technology can be more or less easily entertained, the *social acceptance* of the eventuality of nuclear accidents is very low – much lower than for any other possible type of accident.

This fact is perhaps what prompts nuclear technocrats and politicians to provide themselves and others with a reassurance that nuclear accidents are not supposed to happen. More precisely, there are strong pressures from all sides to produce probabilistic risk evaluations that *fit the level of social acceptance of nuclear accidents.* It is common to analyze the relationship between the public, on the one hand, and nuclear technocrats and government, on the other, in terms of opposing interests. At some level, however, the relationship is de facto of a *collusive* nature: low social acceptance produces low risk probabilities.

This deep-level relationship is cast in terms of a tacit contract, and the contracting parties are unaware of its nature. Nuclear energy proponents and the public, with its attitudes ranging from support of to opposition to nuclear energy, are bound by one absolute threshold agreed to by all parties: core radioactive material is to be confined, without the possibility of escape, no matter what type of system function or dysfunction may be experienced. This clause of the tacit contract was enacted in the 1970s, at which time appropriate containment equipment was installed in many plants.

However, the unforeseeable combinations of technical characteristics and human factors can defy, in certain cases, any large engineered system. The collective, wishfully low estimate of nuclear risk unfortunately is not a self-fulfilling prophecy. A silent agreement, which can function as symbolic protection, is powerless to act as a real protection in the area of technology and its failures.

Thus, the accident at TMI struck a first blow to this social contract. It has become apparent that a loss of control occurred during the operation of the plant, causing a partial meltdown. Safety backup systems did, however, function, and only a minuscule amount of radioactive material was released into the environment.

In the case of Chernobyl, a chain of human errors resulted in not only a loss of control within the plant, but also a release of great quantities of radioactivity to the outside. This struck an even more severe blow to the social contract, in that it gave reality to the "worst case" of a reactor meltdown and burnthrough with large-scale open-air release of radiation. Thus far this had been a uniquely theoretical event, pushed by probabilistic calculations to a distance of one billion reactor years, though seen as much more looming by opponents of nuclear energy. The apparent will to see probabilistic projections coincide with social acceptance is present in the US Nuclear Regulatory Commission's (NRC) pronouncement in 1985: A TMI-type accident might occur once in 3,300 reactor years; a "worst case" accident in one billion reactor years. In fact, the TMI accident occurred rather early in the series for most people to accept, at about 400 reactor years in the USA. The USSR had some 450 reactor years in operation when the one-in-a-billion accident occurred.

This points to the fact that the Chernobyl accident not only is difficult to cope with, as with any other human-made disaster, but also represents the rupture of a very special social contract that carried the strength of the converging needs and wishes of all parties.

When this rupture occurred, the reactions of anger, outrage, and fear appeared to be in inverse proportion to the social acceptability quotient. Having a flat tire on one's car, short of a blowout at high speed, is quite high on the social acceptability scale, though it signifies a rupture of the contract engaged when a person acquires a car believing it is apt to present few operational problems. When the tire is found to be flat, most people can accept the fact with only annoyance (high social acceptability–low affective impact). The social acceptability of a nuclear accident, in contrast, is so very low that reactions to such an accident are that much more laden with distress.

8.3.2 The loss of a socially valued object

Often, when analyzing the impact of disaster, reference is made to loss: loss of control, loss of confidence, loss of credibility, etc. We will look at a level of loss that supersedes these others: the loss of nuclear technology as a valued object.

According to Ellul (1987), who has traced since 1954 the social mutations caused by technology, our societies have been subject to the charm of technology to the point of no longer knowing how to make use of good sense. Nuclear energy, along with space exploration, is a hallmark of the twentieth century. It has taken over, receiving collective projections of being an all-powerful ideal object, constructed by belief systems impermeable to facts, and consolidated by the silent agreement described above. Nuclear power can be an object of national pride, the symbol of high-tech achievement and one's control of forces stronger than oneself. (In France, for instance, some 250,000 to 300,000 persons visit and tour nuclear plants each year.) In the practical sphere, it has undeniable benefits for societies demanding reliable, cheap, and abundant energy.

In this light it is easy to conceive that the loss of this collectively idealized technology through the Chernobyl accident triggers deep responses that cannot be approached by direct inquiry or overt surveys. We must, thus, search elsewhere for information on the process of loss. Research has been conducted on human and social experience in facing the loss of a valued object: one's own life, a close relative or friend, or a limb or one of the senses. Our working hypothesis is that findings in this field can probably help us understand the human and social experience of loss of confidence and credibility in nuclear power, and the mechanisms involved.

A major finding is that there are several interrelated steps in facing the loss of a valued object. Sometimes the process appears to be cyclical, in that it involves shifting back and forth between different states of mind and emotions.

Table 8.2 provides a summary of the four major models in the literature of loss. It must be stated that not everyone goes through each stage in a personal experience of loss. Furthermore, undoubtedly other variables occur during the social reactions to a large accident like Chernobyl, notably those linked to interpersonal interactions, large group dynamics, information processing, and so forth. Nonetheless, it seems useful to look at these stages; deeper responses are too often simply termed as being "irrational." Emotional responses to nuclear energy are often cited, but seldom analyzed.

According to the models of *Table 8.2*, the first individual reaction following the loss of a valued object varies: numbness, denial, shock, feeling of detachment. This corresponds to what has sometimes been reported following the Chernobyl accident and can explain, at least in part, various observations.

Table 8.2. Stage models showing responses to the loss of a valued object.

Shontz 1965, 1975	Kübler-Ross 1969	Bowlby 1980	Horowitz 1976, 1985
1 Shock; feeling of detachment	Denial	Numbness, feeling of being stunned	Feeling of being stunned; denial
2 Encounter; experience of helplessness, disorganization, panic, reality seems overwhelming	Anger	Yearning, searching, urge to recover the lost object; anger	Intrusion of the reality of the loss
3 Retreat; avoidance	Bargaining	Giving up attempts to recover lost object; disinclination to look to the future	Coping
4 Adaptation	Depression	Breaking down attachment to lost object; establishment of new ties to others	
5	Acceptance		

These include a certain slowness of officials to act, absence of apparent reaction among some parts of the population, and denial of the accident and its effects: "such an accident is not possible ...cannot happen here ...the cloud of radioactivity will not reach our borders."

The next step seems marked with reactions that demonstrate coming to grips with the reality of the loss. This can be expressed by anger, panic, or attempts to recover the lost object. Horowitz (1976, 1985) points to a back and forth movement between this stage and the previous one. This indicates that affect and cognition are linked in a rapid feedback loop, with one term prevailing at any time over the other. It indicates also that reactions are not a linear process.

Eventually these stages give way to adaptation, coping, acceptance, and establishment of new ties with other objects. In concrete terms, what does this point to in the case of nuclear accident? Two distinct alternatives fit the adaptation profile. One is that social acceptance of a possible nuclear accident – at present, extremely low – can gradually rise, showing a better tolerance for risk after passing through the test of reality. Alternatively, nuclear energy can gradually be given up and other options explored.

Not all individuals go through all the stages, nor at the same speed. Some stages may be skipped; others may never be resolved. The stages-of-loss perspective on the Chernobyl accident can have important implications for risk communication and crisis management. Denial and anger may seem to dominate in reactions at one time, but are apt to evolve into different ways of coping with reality. Knowing of typical and temporary stages can help in adjusting the type of communication best adapted to an evanescent situation.

A large nuclear accident like Chernobyl might be more of a trauma than individual and groups experiencing it may be aware. In this case, we can expect to find clinically observed patterns of reaction: that is, people are unaware of going through a mourning process and may act out behaviors that seem to them to be perfectly rational and normal. They do not recognize that these reactions may be overdetermined by affect rather than cognition. An outsider, unless highly trusted, is thus not likely to achieve a helpful effect in making direct reference to the irrational nature of the reactions observed.

An evaluation of the stage of loss currently experienced by a victimized population can indicate appropriate content or theme. This raises the point that governments and nuclear energy authorities may not be equipped to address the demand for risk communication. They may lack a certain framework for understanding victims' needs, above and beyond the fact that they are likely to give first priority to other tasks (e.g., reevaluating the future of nuclear energy).

In effect, these communicators need to understand that the loss caused by Chernobyl is double. Populations are not only blaming those who were supposed to be in control of nuclear power and who might be overestimating its safety status. They have also lost nuclear power as a socially valued object – one that had been invested with beliefs of being safe, useful, positive, glorious, and infallible. The current credibility crisis not only is directed toward the individuals and groups controlling nuclear energy, but, much more deeply, addresses the collective image of nuclear energy itself whenever and however it is presented.

8.3.3 The removal of distances

Another specific characteristic of nuclear accidents is the dynamics they entertain with distances. Chernobyl is especially striking in that it has had the effect of radically removing a variety of distances. Be they geographic or national, corporeal or fantastical, economic or social, many slowly built and firmly installed distances have suddenly collapsed.

Geographic and national distances. The toxic release at Chernobyl has been widely commented on for its "transnational" character. For many days, radioactive clouds covered wide areas, crossing and recrossing numerous borders and frontiers, regardless of national and political characteristics. The differences in official attitudes toward nuclear energy in Europe became apparent in the measures set up in each country: radiation levels varied drastically from one national border to another.

Even in 1986 the European Community (EC) was preparing to abolish economic borders and open a vast common market. Nevertheless, the sudden levy caused by the Chernobyl accident, producing universal equality under a radioactive cloud, came as a shock. The protective role of frontiers – those official and legal limits, markers of where proximity becomes invasion, historically established through countless wars and treaties – suddenly ceased. Abrupt closeness was created with a common and pervasive invader. Europe was not ready to cope with the unanticipated demands of transnational solidarity. Will Chernobyl ultimately have a positive outcome of making Europeans realize how close together they actually are?

Political distances. The Director of the International Atomic Energy Agency, Hans Blix, said in November 1986, "Chernobyl showed that a serious accident anywhere has consequences for nuclear power everywhere." Until that time, each country developing this energy source enjoyed a large measure of sovereignty in the design and order of the nuclear program. The technology was managed in accordance with the political, economic, and social principles and projects of each nation. This sovereignty was challenged by Chernobyl, leaving countries to deal with the aftermath as if the accident had happened within their dominion, rather than solely in the USSR. Most governments were thrown into a situation requiring not only public health measures but a reevaluation of nuclear power's cost and energy alternatives. The autonomy of each nation to make decisions regarding nuclear energy was called into question, effectively destroying the social and political balance typical to each country. This removal of difference is a blow to national identity.

Social distances. Other well-established distances that were removed were those linked to the division of labor throughout the social structure. Since the beginning of time, and especially since the industrial revolution, energy production has had human and social costs. For instance, coal mining's painful history of casualties is not over; family groups and communities have seen their history made by the economic pull of the mines and the deaths and disabilities that often result. Outside groups, though, were not directly concerned. Nuclear operators and related professionals, like other industrial workers, encounter some context-dependent risks on-site. Indeed, the immediate casualties at Chernobyl were among fire fighters and operators.

The threat exists, though, that all social groups, at all levels, can be affected by a nuclear accident. No longer do the groups charged with energy production bear all the burden of its cost. Those groups whose high living standards were assured by cheap and plentiful energy suddenly find themselves unwillingly sharing the risk involved in producing it. Such radical removal of social distances cannot come about without being aware of the division of labor and the inequalities inherent in the system. This is a trauma in just that measure to which individuals as members of their society expend a sort of energy in keeping these inequalites out of view.

Stigmatization distances. Social psychological research on stigma (Goffman, 1963) describes the social dynamics and relationships in which a particular mark is defined as shameful or discrediting. Social groups distance themselves from other groups identified as being afflicted in some way. The basic motivation to such phenomena is to maintain distance with some life- or identity-threatening characteristic. This often is observed in health-related risks, where the notion of "risk group" appears. The illness can be thought of as being the shameful dues of membership in the risk group; in this way, nonmembers can feel safe from the illness.

The Chernobyl accident can be seen as a stigma, concentrating on images of danger and death. It happened to occur in a setting already stigmatized in a certain way: Western countries tend to reject the USSR as having an unacceptable political and social system. Thus, it is easy at first to attribute the accident to the characteristics of the out-group: "Chernobyl happened because the Soviets are backward in technology." In such a perspective, the events of Chernobyl confirm everything that has been rejected in the Soviet system.

Such victim blaming, though, in the case of Chernobyl, could not be maintained. The impact of the accident far overflowed the borders of the stigmatized group. Other groups could not avoid the perception of sharing characteristics with the afflicted setting: nuclear technology is too close to home, the magnitude of its risk too great to be contained by one rejected out-group.

Thus, the trauma suffered could not be sent away as the discrediting affliction of others. Individuals and groups are deprived in this situation of this important protective mechanism. The effects on the individual afflicted with an illness he had convinced himself was impossible to acquire are known: they are shattering. The effects upon society of the collapse of stigmatization distances must now be observed.

Personal distances. The confrontation with a situation in which toxic radiation has been released puts people in the presence of an invisible threat that cannot be felt or stopped. In addition to national boundaries and social distances being trespassed, an ultimate limit is swept aside: that of the private distance between inside and outside. Some observations have been made of how individuals manage their psychological privacy, as if distancing access to the inner self with successive rings. Subtle social and personal customs regulate communications across these nested rings; the person can slow or even stop the circulation of information from the deep self toward the outside or from the outside toward the self. The violent news of an accident like Chernobyl can make these inner limits fall abruptly. Bad news flows inward; anxiety flows outward. The feeling of loss of control, of the environment, and of communications with it is a documented trauma. In this way the disaster is like rape or torture.

Research on "cognitive maps" has shown the way in which people represent the layout of their world to themselves. The image of a nuclear plant in an emergency is a feature that had been absent or very far away in most people's cognitive maps. The Chernobyl accident suddenly brought a faltering Soviet plant extremely close to home, as if it had sprung up in one's garden.

The existing state of social attitudes and mental frameworks regarding nuclear technology is of great importance in shaping deep reactions to a major nuclear accident. Tacit social agreement, attachment to an idealized object, established and structured distances are all global social facts existing before the nuclear accident itself. The accident actually has the effect of revealing to numerous members of society how magical and inoperative the tacit contract is, how frail the idealized object is despite its power, how artificial many social distances are. We can suppose that these constructions served to protect us from the intrusion into everyday life of the "fundamental anxiety" (Schutz, 1962) linked to the reality of death and our mortality. A nuclear disaster confronts the issues of death and illness, already faced by individuals and groups involved with nuclear power. Such open confrontation with this inescapable anxiety is part of the dynamics triggering a generalized credibility crisis.

8.4 The Future of a Credibility Crisis

In Section 8.3, I investigated the major elements that form the basis of the long-term reactions to the Chernobyl accident. Among those reactions is the loss of credibility.

A credibility crisis – articulated upon the rupture of a tacit contract, the loss of a valued object, and the removal of distances – is a slow, unfolding process. A way to portray it is first to describe a state of generalized conflicting cognition. From that confusion can emerge a capacity to look in a more lucid manner at the cost of nuclear energy. Other positive consequences of the credibility crisis following the Chernobyl accident are the identification of those social conditions best able to address the very specific demands nuclear energy puts upon individuals and groups. Finally, the fact that we know better now what a nuclear disaster looks like can enable us to organize more appropriate primary prevention programs in the case of another disaster.

8.4.1 A generalized state of conflicting cognition

Before the Chernobyl accident, the global social situation could be briefly characterized as simultaneous high-level anxiety about atomic radiation and high expectations for the safety of nuclear installations. The way in which these simultaneous attitudes gave forth a very special silent agreement between the public and nuclear officials, wherein risk probabilities were apt to be adjusted to the social acceptance level for nuclear accidents, was explored earlier.

This underestimation of accident potential was not, however, a voluntary attempt by nuclear power authorities to manipulate the public. Rather, it seems to rest upon an avoidance of conflict at a deeper level. The deeper characteristics of the preexisting social situation are apt to be just as important as the characteristics of the accident itself, when looking at what follows. Some of the mechanisms at work to produce a silent agreement can be traced in terms of typical defensive reactions.

Studies have shown that the high level of anxiety among the public can be related to the following:

- The physical properties of nuclear energy, mostly as an invisible threat.
- Previous use of atomic energy in wartime to aggress and destroy populations.
- Continuous presence of a nuclear strike force as a dissuasive weapon [see, for instance, Simon's (1984) apocalyptic scenario of the "nuclear winter" that follows a massive nuclear strike].

Some researchers (Fornari, 1969; Guedeney and Mendel, 1973) have tried to link the fear of the atom to myths: the myth of the Apocalypse, corresponding to a final destruction of the world; the myth of Prometheus, punished for having stolen the fire of the gods; the myth of the almighty power of what is infinitely small like the atom and uncontrollable in its action toward man.

These elements have led to a splitting of nuclear images in the public's attention. Two relatively independent conceptual images exist: positive (nuclear energy production) and negative (destruction by nuclear energy). These two valences of nuclear energy cannot be psychologically merged to one social image. Individual and social defenses are set up against such a holistic image, to protect not only from the notion of the destructive power of this technology, but from the destructive power of the *fears* that are inspired by that notion. The destructive potential of "positive" nuclear energy production is, thus, often deeply buried, so as never to have to be entertained by the mind.

Obviously, certain persons are directly confronted with the immediate reality of nuclear power and its risks: persons living close to power plants, for example. The paradoxical results of some surveys demonstrate the type of defensive reaction described above: the closer a person's home is to a plant, the more that person minimizes nuclear risk (in contrast to persons living farther away who are more open to recognizing the risky character of the technology). Those persons living close by have, in fact, resolved the tension resulting from the cognitive conflict created by living in the proximity of risk. The perceived importance of one term of conflict is simply reduced. This type of conflict resolution is typical in cases of "cognitive dissonance" (Festinger, 1957).

The reaction of these individuals can also be seen in terms of human handling of complexity. Studies indicate that people can avoid facing contradictory data. Kahneman and Tversky (1984) have shown how people, when asked to evaluate risk, provide different preferences according to the way in which the situation is "framed." This tendency is reflected in "self-framing" whereby the individual perceives situations in such a way that the "best" choice to be made will, in fact, automatically be consistent with prior sets of beliefs.

It can be said that all social systems gain in strength through facing and coping with a crisis. The Chinese ideogram for crisis reads "opportunity blowing in the wind." For a crisis not to endanger the survival of a social system, it is important that there be present some capacity to handle contradictory information and conflictual situations. Indeed, many aspects of social life are ridden with contradiction. In a way, this is proof that society has that "survival" potential.

Some resolutions of conflict and crisis can tend toward oversimplification, like those resolutions described above. The political tendency may have been to cover up the negative aspects of nuclear energy, thus playing to and reinforcing the individual's needs for protection against fundamental anxieties that can be triggered by nuclear energy (see Jaques, 1955). On the social scene, oversimplification was apparent in the superficial opposition of two groups: those seeing only positive aspects of nuclear energy, and those seeing only the negative. Such a dramatic, visible polarization limits the possibility of accepting a more complex vision of the object in question.

8.4.2 Positive consequences of the credibility crisis

Another type of outcome of a crisis can be a better grasp on reality and on its complex nature. One positive consequence of the Chernobyl accident may be that the image of nuclear energy becomes more complete for all involved – for all of us. A more complete image would retain its contradictory characteristics: nuclear energy has both positive and negative sides.

This type of more complex and less reductive cognition in the public may not alter much the probability of a nuclear accident. I have argued elsewhere, though, that nuclear operators with a better grasp of the complexity are better equipped to handle system crises (Poumadère and Guinchard, 1986). If the need to deny or to see lowered probabilistic evaluations of risk could be reduced, though with a more complex view on things, the basis of institutional decision making about nuclear operations would be altered, perhaps for the better. Experts in systems reliability (e.g., Villemeur, 1988) try to include these dimensions of human factors and decision making in their reliability methodology.

A more complete and complex image of nuclear power could indicate, too, a better preparedness of the public for the eventuality of an accident. We would be less vulnerable to the psychological trauma that occurs when the possibility of destruction we worked so hard to repress suddenly surges forth in reality. Less vulnerable psychologically, we might be able to respond better to the physical trauma implied by a nuclear accident: with community evacuation planning, medical preparedness, and overall solidarity with those who are closest to our energy production. All in all, the ability to consider the risk associated with nuclear power would keep us in contact with all the realities incumbent on this social and economic energy choice.

For such a realistic attitude to be developed, it is highly important to talk about Chernobyl. This accident should not become taboo, an isolated freak occurrence that never should have happened and that should be ignored. Such social amnesia is a risky outcome of the credibility crisis. To reduce this risk, effort should be made to ask important questions: Can we realize all the implications of the accident at Chernobyl? Can we be better prepared for the next occurrence?

Whatever decisions are made to maintain, slow down, or end nuclear energy programs in Europe as a result of Chernobyl, more social solidarity toward nuclear workers is essential. It is only just to recognize the contributions of these members of society. Justice, though, may not be sufficient motivation for an evolution of public attitude.

If nuclear energy remains a social issue debated in a conflictual, unrealistic atmosphere, whereas concrete reality continues to be characterized by a high level of nuclearization, as in France, nuclear workers could be too psychologically mobilized by the reduction of this cognitive dissonance. The cost of this psychological and social defense effort within the plant is likely to be too high, leading to augmented stress and risk of error.

Risk communicators should work toward social solidarity as an outcome of the credibility crisis: this can be a favorable factor for nuclear workers in carrying out their jobs, thus reducing the probabilities of another Chernobyl occurring soon. This communication task is not simple: we can expect resistance on all sides, given the strength of social distances that divide labor and distribute roles in our societies.

Another level of positive consequence of a credibility crisis is that it forces individuals and groups to face the reality of nuclear disasters. Although this "face to face" is painful and traumatic, it is a necessary step to help organize society to cope with such undesirable reality.

Although the mythology surrounding nuclear energy will not disappear overnight, the occurrence of nuclear disasters might have the paradoxical effect of revealing the down-to-earth dimension of this creation. Moreover, this should lead to better appreciation of its place and role in society, both when it works and when it does not.

8.4.3 Organizing primary prevention in nuclear disasters

Evacuation plans for areas neighboring nuclear power plants and provisions for medical assistance are necessary. The Chernobyl accident has stimulated efforts in this direction. Those who insist upon improving coordination and decision-making effectiveness within the networks involved are to be encouraged. However, these lifesaving plans may not be enough.

Two strong implications for policy response to large accidents emerge from this study of the Chernobyl accident. The first issue is that of defining victim groups. Traditionally, victims of a catastrophe would be defined as those who were physically touched by its effects. We have tried to demonstrate that the definition of victim might need to be extended to all those who received the bad news.

The second issue involves minimizing the damage caused by a credibility crisis and related mental and social turmoils, once a nuclear disaster has occurred.

An extended definition of victim leads to the realization that no one centralized organization, however perfectly coordinated, can deal with hundreds of millions of victims. This points to the need to decentralize primary prevention far below the national government level.

In a very interesting study, Deicher *et al.* (1988) report on a decentralized risk-management action in the Constance region in southern West Germany. This is an area where no nuclear emergency plans existed. The action described took place in response to Chernobyl and involved multiple initiatives. Radiation levels of milk and vegetables were monitored; more than 100 public talks were organized with graduate students presenting radiation risks information. The local newspaper offered a forum for inquiry (500 letters were received from the public); scientists responded to these questions and contributed other articles. A telephone hot line was also set up. The authors of the study report that the individuals involved in the measurement and communication processes did not overreact (thus refuting a common argument in favor of centralized action) and that the local population benefited from the establishment of effective local countermeasures.

A decentralized approach was effective in designing more appropriate countermeasures and in providing needed specific information. Such a decentralized process has other positive aspects as well. We believe that this direct community involvement was intrinsically helpful, helping citizens to cope with and master the traumatic event. The decentralized action met some of the mental-health needs of the local population in a way that a distant campaign could not achieve.

In a study of primary prevention in aircraft disasters, Williams *et al.* (1988) point out that as early as World War I some basic principles had been discovered in the treatment of "shell shock": treatment effectiveness was a function of immediacy, proximity, and expectancy. Effective treatment included immediate response to emotional problems, close to the place where the person was victimized, and expectations by the caregivers that the victim would recover completely. Treatment characterized by these dimensions led to fewer long-term psychiatric casualties than among victims who were evacuated from the front and treated closer to home.

In the event of a nuclear disaster, the implication is that victims will require mental-health care in the local community. The type of emotional or psychological problems we have evoked might ideally be treated where they occur: at work, at school, within the family. Such a prevention strategy is very different from present disaster response strategies, which favor centralized control and give no attention to the emotional trauma of the victims.

Policymakers who do not believe that Chernobyl will be the last nuclear disaster must take numerous and challenging steps. For example:

- Encouraging and unifying community-level risk management initiatives.
- Assessing specific training needs for health service professionals and others who provide immediate local help; this assessment should access all resources in rural, urban, and organizational or institutional settings.
- Identifying individuals and groups who can offer help immediately; Deicher *et al.* (1988) gave the example of university science faculty and graduate students; university psychology departments among others could also be solicited.

The distance between current disaster resources and such a decentralized network is tremendous. These goals might help focus policymakers' attention on the issues that must be addressed.

8.5 Conclusions

Society is not ready to cope with a nuclear disaster. This type of human-made disaster plus the special social characteristics of nuclear technology trigger unique deep reactions.

An issue raised in this chapter is that the notion of "victimized population" might best be extended to include all the populations that receive the "bad news." Each population has been subjected to the worse effects of the accident, and suffers from a credibility crisis – the dimensions of which are little understood by the public at large.

At present, the greatest policy need may be for help to adjust to the extent of the victimization. This adjustment can be based upon more knowledge of the crisis phase each population is coping with at a given time.

At this point in the credibility crisis, a generalized state of conflicting cognitions is probably prevalent, along with possible individual and social pathologies. These cognitive conflicts and emotional traumas are linked to both the characteristics of Chernobyl as a human-made disaster and the specific nature of Chernobyl as a nuclear disaster. I have identified three major elements as constituents of this nature: the rupture of a social contract, the loss of a socially valued object, and the sudden removal of established distances. Further research and basic information are needed in this area where little specific observation is reported. A better grasp of the impact of nuclear energy on our societies can lead to better adapted policy, increased local and social solidarity, more decentralized initiative and risk management, and better organized primary prevention in nuclear disaster.

Without concerted effort, though, this better understanding could stay out of reach. Social amnesia may well cover up Chernobyl as if it had not happened. Some researchers report that public opinion in Europe is regaining its pre-Chernobyl position. This eventuality should not be regarded by anyone as good news; it may signify that social amnesia is developing. In this case, Chernobyl will have served for little in terms of learning, preparedness, and social solidarity.

Note

[1] This chapter was written in summer 1988; in June 1990 the author participated in a WHO Working Group on the "Psychological Effects of Nuclear Accidents," held in Kiev at the All-Union Scientific Center for Radiation Medicine. Part of the data presented at the meeting unfortunately confirms our hypothesis: an estimated 10 million people in Byelorussia, the Ukraine, and Russia are judged to suffer from the indirect effects of Chernobyl.

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Appendix: Concepts, Units, and Terminology

Radioactivity and Radiation

Both radioactivity and the radiation it produces existed on earth long before life emerged. Radioactive materials became part of the earth at its very formation. Even human beings are slightly radioactive, for all living tissues contain traces of radioactive substances. Toward the end of the last century humanity first discovered this elemental and universal phenomenon.

By far the greatest part of the radiation received by the world's population comes from these natural sources. People are irradiated in two ways: externally and internally. Radioactive substances may remain outside the body and irradiate it from the outside or they may be inhaled or ingested, and so irradiate the body from the inside.

Over the last few decades man has artificially produced radioactive substances, several hundred types of radionuclide. And he has learned to use them for a wide variety of purposes from medicine to industry, from detection of fires to illuminating watch dials. All these increase the radiation sources to which both individuals and mankind as a whole are exposed.

The unit of radioactivity

A few naturally occurring substances consist of atoms which are unstable – that is, they undergo spontaneous transformation into more stable product atoms. Such substances are called radioactive, and the transformation process is known as radioactive decay.

The decay of radioactive material is statistical in nature, and it is impossible to predict when any particular atom will disintegrate. The time, however, that is required for one-half of the nuclei in a sample of a particular radioactive isotope to decay is constant and characteristic of the radioactive species given. Until the introduction of the International System of Units (SI), the unit of radioactivity was the curie (Ci). The curie was originally related to the activity of one gram of radium, but the definition was later standardized as 3.7×10^{10} nuclear disintegration (dis) per second, which is almost the same.

A disintegration usually involves the emission of one or more charged particles, such as alpha particle or beta particle. These may be accompanied, though not

Table 1. Relationship between curie and becquerel.

Amounts		Surface activity levels	
Ci (old)	Bq(new)	μCi/cm^2	Bq/cm^2
1 pCi	37 mBq	10^{-6}	0.037
27 pCi	1 Bq	3×10^{-6}	0.1
1 nCi	37 Bq	10^{-5}	0.37
27 nCi	1 kBq	3×10^{-5}	1.0
1 μCi	37 kBq	10^{-4}	3.7
27 μCi	1 MBq	3×10^{-4}	10.0
1 mCi	37 MBq	10^{-3}	37.0
27 mCi	1 GBq	3×10^{-3}	100.0
1 Ci	37 GBq	10^{-2}	370.0

always, by one or more gamma photon emissions. Some radionuclides emit only X or gamma radiation.

The SI unit of radioactivity is the becquerel (Bq), which is defined as one nuclear disintegration per second. Compared with the curie, the becquerel is a rather small unit. In practice, it is often convenient to adopt the usual multiplying prefixes, for example,

1 becquerel (Bq) = 10^0 dis/s
1 kilobecquerel (kBq) = 10^3 dis/s.

The relationship between the old unit and the new SI unit is illustrated as follows:

$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq} = 37 \text{ GBq},$
$1 \text{ Bq} = 2.7 \times 10^{-11} \text{ Ci} = 27 \text{ pCi}.$

This relationship is clarified in *Table 1.*

Radiation units

Just as heat and light transfer energy from the sun to the earth, so does ionizing radiation transfer energy from a source to the absorbing medium. The source of ionizing radiation may be radioactive atoms or equipment such as X-ray machines.

Ionizing is the removal of one or more orbital electrons from the atom. The atom and the electron, so separated, are known as an ion pair, that is, a positive ion (the atom) and a negative ion (the electron). The absorption of radiation in a medium results in ionization, i.e., the production of ion pairs.

In materials, such as the human body, ionization can lead to the breakdown of molecules and the formation of chemical substances that are damaging to the biological material. The harmful effects of radiation on the human body are largely attributable to such chemical reactions.

Exposure

The first widely used radiation unit, the röntgen (R), was based on the ionizing effect of X and gamma radiation in air, and corresponds to the production of ions carrying one absolute electrostatic unit of charge. In SI units the exposure is expressed in coulomb per kilogram (C/kg) of air.

Although the röntgen is still in use to a limited extent, it is inadequate as a universal radiation unit, since it applies only to X rays and gamma radiation and to their effect in air. In practice, the human tissue is the medium of interest and the energy deposition is usually higher in tissue than in air. Therefore, the concept of absorbed radiation dose has been introduced to overcome these difficulties.

Absorbed dose

Absorbed dose is a measure of energy deposition in any medium by all types of radiation. In SI units, the absorbed dose unit is called the gray (Gy) and defined as an energy deposition of one joule per kilogram (1 J/kg). The original unit of absorbed dose was the rad and was defined as an energy deposition of 100 erg/gram, i.e., 0.01 J/kg. Accordingly,

$$1 \text{ Gy} = 1 \text{ J/kg} = 100 \text{ rad}.$$

An exposure of 1 R is equivalent to an absorbed dose in air of 0.00869 Gy or to an absorbed dose in tissue of 0.0096 Gy.

Dose equivalent

Although the quantity of absorbed dose is a very useful concept, the same absorbed dose of different types of radiation does not necessarily produce the same degree of damage in biological systems. For example, 0.01 Gy of alpha particles can do as much biological damage as 0.20 Gy of gamma radiation. This difference in the biological effectiveness must be taken into account if we wish to add doses of different radiations to obtain the total biologically effective dose. To do this we must multiply the absorbed dose of each type of radiation by a quality factor (Q), which reflects the ability of the particular type of radiation to cause damage. The quantity obtained when absorbed dose is multiplied by a quality factor is known as the dose equivalent, the unit of which is the sievert (Sv). This is related to the gray as follows:

$$\text{dose equivalent (Sv)} = \text{absorbed dose (Gy)} \times Q \times N,$$

where N is a further modifying factor which might take into account such characteristics of exposure as absorbed dose rate and fractionation of dose. For the present, the International Commission on Radiological Protection (ICRP) has assigned a value of one to N.

The unit of the dose equivalent was originally the rem, which is 100 times smaller than the new SI unit called the sievert (Sv). Thus:

$$1 \text{ Sv} = 100 \text{ rem}.$$

Table 2. Radiation dose equivalents.

Rem (old)		Sievert (new)	
0.10	mrem	1.00	μSv
0.25	mrem	2.50	μSv
0.50	mrem	5.00	μSv
0.75	mrem	7.50	μSv
1.00	mrem	10.00	μSv
2.50	mrem	25.00	μSv
10.00	mrem	100.00	μSv
100.00	mrem	1.00	mSv
500.00	mrem	5.00	mSv
1.00	rem	10.00	mSv
5.00	rem	50.00	mSv
10.00	rem	100.00	mSv
50.00	rem	500.00	mSv
100.00	rem	1.00	Sv

The value of the quality factor is found to depend on the density of ionization caused by the radiation in the biological tissue. A value of one has been assigned to the quality factor of X and gamma radiation. Beta radiation and electrons cause ionization of a similar density to gamma radiation and so the quality factor is also one for beta radiation and electrons. The Q for protons is 10, and for fast neutrons, alpha, and other multiple-charged particles it is 20. An alpha particle produces about one million ion pairs per millimeter of track in tissue, whereas a beta particle produces about ten thousand per millimeter.

In terms of occupational radiation exposure, the gray and sievert are large units. It is often convenient to have smaller units, and this is done by using the prefixes milli (one-thousandth, m) and micro (one-millionth, μ). The relationship between rem and sievert is shown in *Table 2*.

Effective dose equivalent

Some organs or tissues of the body are more vulnerable than others. A given dose equivalent of radiation is more likely to cause fatal cancer in the lung than in the thyroid gland, and the reproductive organs are of particular concern because of the risk of genetic damage. The different organs and tissues of the body are therefore also given weighting factors. Risk-weighting factors recommended by the ICRP are as follows: gonads (ovaries and testes) 0.25; breast (for both sexes) 0.15; lungs 0.12; red bone marrow 0.12; thyroid 0.03; bone surfaces 0.03; remainder 0.30; total body 1.00.

Once it has been weighted appropriately, the dose equivalent becomes the effective dose equivalent, and is also expressed in sievert. Effective dose equivalent is the dose equivalent weighted for the susceptibility to harm different tissues and organs. The effective dose equivalent has been defined to ensure that the risk is equal either when the whole body is irradiated uniformly or when there is only partial nonuniform irradiation.

Committed effective dose equivalent

Committed effective dose equivalent resulting from an intake of radioactive material into the body is the effective dose equivalent that will be accumulated during the 50 years following the intake, i.e., over the future life span of an individual – "lifetime dose." For the public, it may be appropriate to extend the lifetime beyond 50 years to assess the "lifetime" dose conservatively.

Committed dose equivalent to a given organ or tissue from an intake of radioactive material into the body can also be defined; it is the dose that will be accumulated in the given organ or tissue over 50 years.*

Dose rate of radiation

The gray and sievert are units expressing the total dose of radiation received over any period of time. In controlling the radiation hazard in an environment (workplace or nature), it is usually necessary to know the rate at which radiation dose is being received. Accordingly, absorbed dose rates are expressed in Gy/h and dose equivalent rates in Sv/h. The relationship between dose and dose rate is

$$\text{dose (Gy)} = \text{dose rate (Gy/h)} \times \text{time (h)}.$$

Collective doses

The previous definitions, however, describe only individual doses. If we add up all the individual effective dose equivalents received by a group of people, the result is called the collective effective dose equivalent, and this is expressed in man-sieverts (man-Sv) or person-sieverts (person-Sv).

One further definition must also be introduced, because many radionuclides in the environment decay so slowly that they emit radiation far into the future. This is the collective effective dose equivalent that will be delivered to generations of people over time, and it is called the collective effective dose equivalent commitment.

Note

*In everyday practice, the term dose is often loosely used to mean one of the following quantities: absorbed dose, dose equivalent, effective dose equivalent, or committed dose equivalent.

Terminology

Absorbed dose: Amount of radiation energy absorbed per unit mass of a given tissue. It is measured in grays (1 Gy = joule/kg) or rads (1 rad = 100 ergs/g).

ALARA: As Low As Reasonably Achievable. The effects of radiation and levels of exposure should be kept as low as possible with due regard to economic and social factors.

ALI: Annual Limit on Intake. The activity of a radionuclide that, taken into the body during a year, would provide a committed effective dose equivalent to a person equal to the annual occupational effective dose equivalent limit (0.05 Sv or 5 rem) or, in some cases, the organ dose equivalent limit.

Bq: becquerel. The SI unit for the number of radioactive disintegrations per second: 1 Bq = 1 radioactive dis/s; 1 Bq = 27×10^{-12} curies.

BWR: Boiling water reactor. Nuclear power plant that has a core cooled by water that is allowed to boil in the pressure vessel. It is a thermal reactor that uses water as both a coolant and a moderator.

Ci: curie. Old unit of radioactivity: 1 Ci = 3.7×10^{10} dis/s (27 Ci = 10^{12} Bq).

Collective dose commitment: Sum of the doses to all individuals in a population.

Collective effective dose equivalent: The product of the average effective dose equivalent and the number of persons exposed to a given source of radiation, expressed in man-sievert (man-Sv) or person-sievert (person-Sv).

Committed dose equivalent: The dose equivalent accumulated in the 50 years after intake of a radionuclide, often to age 70.

Dose equivalent: The quantity obtained by multiplying the absorbed dose by a quality factor to allow for estimated differences in effectiveness of the various ionizing radiations in causing harm to humans, measured in sieverts (1 Sv = 100 rem).

Dose rate: Absorbed dose per unit of time (e.g., Sv/year).

Effective dose equivalent: The quantity obtained by multiplying the dose equivalents to various tissues and organs by the risk-weighting factor appropriate to each and summing the products.

Fallout: Radioactive debris from a nuclear detonation, which is airborne or has been deposited on the earth.

Fast reactor: A nuclear reactor where fission is brought about by fast (high-energy) neutrons.

Fuel cycle: The sequence of steps, such as mining, milling, fabrication, utilization, and reprocessing, through which nuclear fuel passes.

Genetically significant dose: The dose that, if given to every member of a population, would produce the same genetic harm as the actual doses received by the various individuals, expressed in sieverts.

Gy: gray. SI unit for absorbed dose: 1 Gy = 1 joule of energy absorbed per kilogram of tissue; 1 Gy = 100 rads.

Half-life: The time for the activity of a radionuclide to lose half its value by decay.

Ionizing radiation: Radiation that can deliver energy in a form capable of removing electrons from atoms and turning them into ions.

Mean dose equivalent: The dose equivalent in each organ or tissue to which the ICRP dose limits for nonstochastic effects apply.

Negligible individual risk level: A level of risk of death (10^{-7}) that can be dismissed. This risk is that associated with an annual effective dose equivalent of 0.01 mSv.

PWR: Pressurized water reactor. A type of nuclear power plant that has a core cooled by water kept under pressure. It is a thermal reactor that uses water as both a coolant and a moderator.

R: röntgen. Old unit of exposure. 1 röntgen = 2.58×10^{-4} coulomb per kilogram of air.

Rad: Old unit of absorbed dose. One rad is 0.01 joules absorbed per kilogram of any material.

RBMK reactor: A type of nuclear power plant that uses low-enriched uranium as fuel, is graphite moderated, and is cooled by light water. It is a channel-type reactor where the water boils in the channels and has a direct steam cycle to the turbine. These reactors are refueled during operation and usually do not have containment buildings.

Rem: Old unit for dose equivalent. The absorbed dose (rads) is multiplied by the quality factor for the particular type of radiation: 100 rem = 1 Sv.

Source material: Uranium or thorium or any combination thereof and ores that contain at least 0.05 % uranium, thorium, or any combination thereof.

Special nuclear material: Plutonium, uranium-233, and uranium enriched in the isotopes U-233 or U-235.

Stochastic effects: Random effects, the probability of which is a function of radiation dose without threshold.

Sv: sievert. The SI unit of dose equivalent. The absorbed dose (in grays) is multiplied by a quality factor for the particular type of radiation: 1 Sv = 100 rem.

Teratogenic effects: Effects occurring in offspring as a result of insults sustained in utero.

Thermal neutrons: Neutrons that have been slowed to the degree that they have the same average thermal energy as the atoms or molecules through which they are passing. The average energy of neutrons at ordinary temperatures is about 0.025 eV.

Thermal reactors: A nuclear reactor where fission is brought about by thermal neutrons.

Whole body dose equivalent: The dose equivalent associated with the uniform irradiation of the whole body.

Abbreviations

ALARA: As Low As Reasonably Achievable
ALI: Annual Limit on Intake
BWR: Boiling Water Reactor
CEC: Commission of the European Communities
CMEA: Council for Mutual Economic Assistance
DAC: Derived Air Concentration
EC: European Communities
EURATOM: European Atomic Energy Treaty
FAO: Food and Agriculture Organization
GSD: Genetically Significant Dose

IAEA: International Atomic Energy Agency
ICRP: International Commission on Radiological Protection
IIASA: International Institute for Applied Systems Analysis
ILO: International Labour Office
INSAG: International Nuclear Safety Advisory Group
MWe: Megawatt-electric
MWt: Megawatt-thermal
NEA: Nuclear Energy Agency
NRC: Nuclear Regulatory Commission
PWR: Pressurized Water Reactor
TMI: Three Mile Island
UNEP: United Nations Environment Programme
WHO: World Health Organization

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Chernobyl: A Policy Response Study reports on how regions, countries, and Europe as a continent responded to the Chernobyl accident. The responses of society to traumatic disasters which change the whole pattern of life on a continent for an extended time period are discussed.

"It is highly important to talk about Chernobyl. This accident should not become taboo, an isolated freak occurrence that never should have happened and that should be ignored. Such social amnesia is a risky outcome of the credibility crisis. To reduce this risk, effort should be made to ask important questions: Can we realize all the implications of the accident at Chernobyl? Can we be better prepared for the next occurrence?" This scientific study is coauthored by a group of prominent scientists from several European countries, who had as their common goal a wish to give a lucid view of the status of scientifically validated knowledge on the risk responses in Europe after Chernobyl.

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