The purpose of this article is to describe and contrast two relationships between radiation and food—on the one hand, beneficial preservation of food by controlled exposure to ionizing radiation; and, on the other, contamination of food by accidental incorporation of radioactive nuclides within the food itself.

In food irradiation, electrons or electromagnetic radiation is used to destroy microorganisms and insects or prevent seed germination. The economic advantages and health benefits of sterilizing food in this manner are clear, and numerous studies have confirmed that under strictly controlled conditions no undesirable changes or induced radioactivity is produced in the irradiated food.

An altogether different situation is presented by exposure of food animals and farming areas to radioactive materials, as occurred after the major Soviet nuclear reactor accident at Chernobyl. This article furnishes the basic information needed to understand the nature of food contamination associated with that event and describes the work of international organizations seeking to establish appropriate safe limits for levels of radioactivity in foods.

The conference for which the initial draft of this text was produced treated two completely different aspects of radioactivity as it relates to food. These were:

1. Preservation of food through ionizing radiation—that is, beneficial utilization of radioactivity; and
2. Contamination of food through exposure to radioisotopes from natural, artificial, or accidental sources—and measures for protecting food against such contamination.

Since the two subjects are quite different, it was originally thought that they should best be discussed separately. However, for various reasons this proved impractical, and so it was decided to consider both at a single conference—which would have the benefit of emphasizing the radical differences between these subjects and would, it was hoped, help to avoid confusion about possible toxicologic effects.

However, it is necessary to note that such confusion does exist in the minds of consumers. Their resistance to accepting irradiated food has been, above all, a product of the emotions derived from the fact that many individuals consider anything associated with nuclear energy to carry with it danger and radioactivity. Furthermore, the terminology used to describe irradiation of foods is frequently confused with that employed to describe radioactive contamination, leading some consumers to believe falsely that they themselves could be exposed to radioactivity by eating irradiated foods, and also to fear that introduction of a new nuclear...
technology could raise the chances for accidents causing environmental contamination or endangering the health of workers. Such fears were notably heightened by the major 1986 accident at the USSR’s nuclear power plant in Chernobyl.

In the health field, not only are radioactive isotopes used daily for diagnosis and treatment, but medical and sanitary products are sterilized by radiation. Indeed, most of the plants now used to irradiate food were originally constructed for irradiation of medical products. And just like medical products, foods treated with radiation under prescribed conditions do not become radioactive in any way. Nevertheless, there are many who do not know this fact or refuse to accept it.

Let us therefore look first at the methods used for irradiating food—including their purposes, advantages, limitations, and control, as well as the types of foods that can benefit from these methods and any possible toxic side-effects that they might have.

FOOD IRRADIATION

Irradiation is a physical method of food processing comparable to methods such as heating or freezing. It consists of exposing food for a limited time to radiation that destroys microorganisms, insects, or vital processes such as germination.

Ionizing radiation’s value for food preservation lies in its capacity to kill microorganisms that are pathogenic or cause adverse food changes and deterioration, to destroy insects, and to hinder germination of vegetable products such as cereals, potatoes, or onions while in the process causing little or no change in the food’s temperature.

Furthermore, for this and other reasons, radiation has certain distinct advantages over conventional food processing methods. Among them:

1. The food can be treated after being packaged and/or frozen.
2. Irradiation permits preservation and more extensive distribution of foods in a state of freshness or near-freshness.
3. Perishable foods can be kept longer without perceptible loss of quality.
4. Once a plant is installed, irradiation’s low cost and energy requirements compare favorably with conventional food processing methods.

Irradiation of foods that lend themselves to this type of treatment has two principal benefits for humanity, one related to health and the other to economics. These are as follows:

1. By destroying certain human pathogens transmitted by foods (such as the almost inevitable Salmonella found in chickens), it makes food safer.
2. By prolonging foods’ useful shelf life, killing pests such as insects, and hindering plant germination, it slows the deterioration of foods, thereby increasing their availability.

It should also be noted that irradiated foods can be particularly useful for certain population groups. Such groups include:

1. People at high risk of contracting infectious diseases—such as hospital inpatients, inmates of homes for the elderly, children in kindergartens, and (especially) patients with incompetent immune systems.
2. People for whom weight and space are important—such as members of the armed forces, astronauts, air travelers, and campers.
Food irradiation also has certain limitations, one of the most important being the high initial cost of irradiation facilities—unless existing installations for irradiation of medical products are available for adaptation to food irradiation.

Types of Ionizing Radiation

In general, the following types of ionizing radiation are distinguished: nuclear particles—neutrons, protons (hydrogen nuclei), and alpha particles (helium nuclei); electrons (cathode and beta rays); and electromagnetic radiation (X rays and gamma rays). Neutrons generate radioactivity in the materials that absorb them, while protons and alpha particles have too little penetrating power to be of practical importance in food preservation. This leaves X rays, gamma rays, and electrons as types of radiation usable in food preservation.

Usable X rays and electrons are produced by appropriate machines, while usable beta and gamma rays are emitted by the radionuclides cobalt 60 ($^{60}$Co) and cesium 137 ($^{137}$Cs). Cobalt 60 is manufactured specifically for use in radiotherapy, sterilization of medical products, and irradiation of foods. Cesium 137 is one of the fission products contained in spent nuclear fuel rods; it must be extracted in reprocessing plants before being employed as a source of useful radiation. At present, almost all gamma ray facilities in the world use $^{60}$Co rather than $^{137}$Cs.

From the point of view of safety, it is important to regulate the level of energy applied in order not to induce radioactivity in irradiated food. For purposes of measuring emitted radiation, the international unit used is the electron-volt (eV), 1 eV being the energy acquired by an electron in moving through a potential of one volt, or $1.602 \times 10^{-12}$ ergs. In practice, the unit used is the mega-electron-volt (MeV), equal to one million electron-volts.

In addition, the effective dose of radiation absorbed must be considered. Originally, the measure of absorption employed for this purpose was the rad (radiation absorbed dose), 1 rad equalling an absorbed energy of $10^{-5}$ joules (100 ergs) per gram of irradiated material. The practical unit is the megarad (Mrad), equal to one million rads. However, the term used by the Sistème International (SI) is the gray (Gy), 1 gray equalling 1 joule per kilogram or 100 rads, with 10 kilograys equalling 1 megarad.

The isotopes commonly used in food irradiation ($^{60}$Co and $^{137}$Cs) emit radiation with a maximum energy of 1.33 MeV. Since this is insufficient to induce radioactivity in foods, control of this variable in practice is only important in the case of instrument-generated radiation.

Wholesomeness of Irradiated Foods

The requirements necessary to ensure wholesomeness of irradiated foods were discussed by the Joint Food and Agriculture Organization (FAO), International Atomic Energy Agency (IAEA), and World Health Organization (WHO) Expert Committee on Irradiated Foods in Rome in 1964 (1). These deliberations indicated that X rays were one acceptable type of radiation produced by instruments. An unedited report presented to WHO by the International Project on Food Irradiation in 1979 (2) also showed that instrument sources of electrons operating below 16 MeV induced only radioactivity of a negligible and very short-lived nature.

On the basis of these two reports, at its last meeting in Geneva in 1980 (3) the committee recommended including sources of X rays and electrons on the list of acceptable sources of radiation. It also en-
endorsed a statement contained in a report of the Joint FAO/IAEA Advisory Group on the International Acceptance of Irradiated Foods (4) to the effect that radiation permitted for irradiation of foods should have a maximum energy level of 10 MeV if comprised of electrons and of 5 MeV if comprised of gamma or X rays.

While irradiation with electrons (at energies up to 10 MeV) or gamma and X rays (at energies up to 5 MeV) does not induce radioactivity, the need for toxicologic evaluation of irradiated foods is justified by the fact that irradiation can cause chemical changes ("secondary reactions") liberating potentially toxic products, and may also prompt undesirable organoleptic changes (of color, taste, and physical properties). The aforementioned Joint Committee meeting in Rome in 1964 (1) adopted the view that such possibly liberated radiolytic products should be treated as food additives. It therefore concluded that the safety of irradiated foods should be confirmed by following procedures similar to those generally used to confirm the safety of food additives and should be implemented by considering the foods one by one.

The nature of the chemical compounds induced by radiation depend primarily on the chemical composition of the irradiated food. The concentration of these compounds generally increases with the radiation dose but can be modified in the course of the irradiation by factors such as temperature, the presence or absence of air, and water content.

The energy absorbed by the irradiated food is much less than that absorbed through heating. Therefore, it is not surprising to find that the chemical changes produced by irradiation are quantitatively much less than those produced by heating. For example, an absorbed dose of 10 kGy (1 Mrad) corresponds to an increase in temperature of only 2.4°C in a food that has the heat capacity of water. This amounts to about 3% of the energy needed to heat water from 20°C to 100°C.

A Joint FAO/IAEA/WHO Expert Committee meeting in 1976 (4) concluded that the radiolytic products detected in a great variety of foods and food constituents that had been studied did not appear to represent any toxicologic hazards at the concentrations detected. The same committee also agreed that in dealing with a dose of less than 10 kGy (1 Mrad), the data could be extrapolated from one article in a given food class to related articles, and that if certain radiation chemistry and toxicology studies were pursued, it would be possible to apply purely chemical criteria in evaluating the wholesomeness of irradiated foods.

On the basis of these findings and new information, at its last meeting in 1980 the Joint Committee was able to formulate a recommendation on the acceptability of foods irradiated up to an average dose of 10 kGy (3). The following considerations led to this recommendation:

1. None of the toxicologic studies performed on a large number of different foods demonstrated the existence of adverse effects as a result of irradiation.

2. It was found that the radiolytic products of the principal components of irradiated foods were identical among themselves and were also identical with the products encountered in foods conserved by other preservative methods.

3. Feeding irradiated foods to laboratory animals, cattle, and immunologically incompetent patients did not result in any adverse effects.

In addition, the Committee considered another initially feared possibility, that of
microbiologic consequences of food irradiation, specifically addressing concern about possible microbial development of resistance to radiation, increased pathogenicity, and induction of mutations endangering human health. All of these matters were duly investigated.

The committee found no risk of inducing major microbial resistance to radiation except under special laboratory conditions. Nor was any case found in which food irradiation applied under proper operating conditions increased the pathogenicity of bacteria, yeasts, or viruses, or induced health-threatening mutations different from those produced by other food preservation methods.

In sum, the committee concluded (3) that irradiation of any food item with a total average dose of 10 kGy posed no special nutritional or microbiologic problems and presented no toxicologic risks; therefore, there was no need for further toxicologic testing of foods so treated. Nevertheless, the committee insisted on the need to carefully analyze any significant change related to each particular irradiated food and to its effect in the diet.

Based on these findings and recommendations, up to the date of writing of this article some 32 countries had given limited or unconditional approval for consumption of more than 40 irradiated food products. In general, these foods are treated in multipurpose industrial installations that were initially constructed for radio sterilization of medical, pharmaceutical, and biological products—a technique that preceded commercial food irradiation by some 20 to 25 years. A total of 140 installations around the world are dedicated, at least in part, to these commercial applications.

Under the auspices of FAO, IAEA, and WHO an International Consultative Group on Food Irradiation was established on 9 May 1984 to assist member states in evaluating and applying food irradiation technologies. The group’s principal objectives are to evaluate the global evolution of food irradiation and provide international agencies and their member states with a central point for consultation about application of this process.

At present 26 governments, half being governments of developing countries, belong to the group and contribute to its activities. Between 1984 and 1989 the group met five times. In addition, on 12–16 December 1988 an international conference on the acceptance, control, and trade of irradiated foods was held in Geneva under sponsorship of the group’s three parent organizations, the United Nations Conference on Trade and Development (UNCTAD) International Trade Center, and the General Agreement on Tariffs and Trade (GATT).

It should also be noted that the FAO/WHO Codex Alimentarius Commission has issued a Codex General Standard for Irradiated Foods and Recommended International Code of Practice for the Operation of Radiation Facilities Used for the Treatment of Foods (5).

At this stage, types of food irradiation offering the greatest health benefits would appear to be treatment of refrigerated or frozen poultry to destroy Salmonella and Campylobacter, treatment of pork to inactivate Trichinella larvae, and decontamination of spices and other food ingredients. Treatment of frogs’ legs and frozen shrimp destined for export also has considerable potential for reducing public health risks.

In conclusion, compared to traditional food treatment methods, irradiation has certain concrete advantages. However, the technique offers no panacea for the whole broad spectrum of existing food preservation problems, and so it should be seriously considered only in those

3Chemical transformation, e.g. oxidation.
specific circumstances where it offers clear advantages over the other methods.

CONTAMINATION OF FOOD BY RADIOACTIVE MATERIALS

The Chernobyl Disaster

As already noted, public fears of environmental contamination (including food contamination) by radioactive products were heightened by the explosion in the Soviet nuclear power plant at Chernobyl, about 130 kilometers to the north of Kiev, capital of the Soviet Ukraine. It was, like that of Bhopal, one of the largest industrial catastrophes in history, and the details have been described in numerous publications, some of which appear in the list of references (6-22).

Our purpose here is not to present the accident's particulars and technical details. Nevertheless, it is fitting to outline briefly its causes and effects, amply described by the Soviet authorities in a report to the IAEA, along with the measures taken subsequently by international organizations to arrive at a balanced understanding of the present situation and possible future actions needed to deal with radioactive contaminants in foods.

The nuclear station at Chernobyl is the largest in the Soviet Union. At the time of the accident it consisted of four functioning reactors and two more under construction. Each working reactor, of a type designated RBMK-1000, could produce 100 MW of electricity, sufficient to illuminate an entire urban area such as Guatemala City. The reactors used enriched uranium (1.8-2.0% $^{235}\text{U}$ with respect to the principal isotope $^{238}\text{U}$) for fuel, this being contained in zirconium tubes; the reaction was moderated by graphite control rods with a total weight of 1,500 tons and was cooled by ordinary water. The heat produced by the fission reaction caused water to boil in a series of tubes, which directed the resulting steam to the turbines of electrical generators.

Ironically, the calamity occurred as a result of a "safety" test, one apparently conducted without authorization by incompetent employees, in the course of which six serious errors were committed. According to the official report, on 25-26 April 1986 the technicians involved were trying to determine how long the generators would continue to function as a result of inertia in the case of an unforeseen reactor shut-down. To prevent the automatic safety systems from interfering with the experiment, the technicians disconnected them, at the same time reducing the energy in Reactor No. 4 to 7% of the maximum.

Unfortunately, this type of reactor has the characteristic of becoming extremely unstable when operating at very low energy levels. As a result, the energy in the reactor increased suddenly to roughly 100 times the operating maximum, converting the water present into steam. The steam in turn ruptured the tubing and reacted with the graphite in the control rods, producing hydrogen, which then reacted with oxygen in the air, producing an explosion with the force of about 1,000 kg of TNT. Some reports also indicate that the steam reacted with the fuel tubes' zirconium in the same sequence—production of hydrogen, reaction with oxygen, explosion.

In any event, the uranium rods disintegrated, the reactor exploded, the concrete roof flew up in the air, and an intense fire broke out in Unit No. 4 when the superheated graphite control rods came into contact with the air. The building, the equipment, and the reactor core were all significantly damaged. A substantial quantity of radioactive material (approximately 3% of the total—basically
fission products) was flung into the atmosphere. Despite heroic efforts by firefighting brigades and various rescue groups, the fire in the reactor continued burning until 5 May.

Two people died during the explosion itself and 500 were hospitalized with various types of acute irradiation syndrome. Twenty-nine of these subsequently died. The number of ensuing cases of cancer, abortion, and genetic or teratogenic effects remains uncertain.

After considerable delay, some 116,000 people living within 30 kilometers of Chernobyl were evacuated. All their possessions (including domestic animals) were left behind. It is estimated that 24,000 of these evacuees received significant doses of radiation.

Partly because of the high temperature generated by the explosion, a substantial "plume" arose that carried radioactive material to altitudes ranging from several hundred meters to over a kilometer. This material was later deposited as "radioactive rain" on the ground—primarily to the west, northwest, and northeast of Chernobyl itself (that is, in the Ukraine). Other portions of the radioactive residue that escaped on 26 April fell principally on northern Europe (Sweden and Finland), with radioactive precipitation being recorded in Poland and the Baltic Sea before noon on 27 April, and in Austria, southern Germany, Switzerland, eastern France, the Benelux countries, Great Britain, Denmark, and the North Sea between noon and midnight the same day.

Subsequently, much of the radioactive plume was carried to the east for some time. It then changed direction and for roughly a day and a half (beginning on 29 April) passed over the Balkans, Italy, Austria, Federal Republic of Germany, France, Spain, and Portugal. Later, another change in the winds resulted in a clockwise circulation transporting the emissions to the east and southeast, where they reached the Black Sea and Turkey beginning on 2 May (6–11).

The sort of atmospheric contamination described here can produce human exposure to radioactive substances in various ways. These include external bodily exposure to the radioactive plume and substances deposited on the soil; internal bodily exposure through inhalation of radioactive products; and further internal exposure to radioactive substances ingested in contaminated foods (or less frequently, contaminated water).

Noble gases in the plume itself produce gamma and beta radiation, but this contributes little to overall exposure, most of which results from solid radioactive materials. Products responsible for most of the latter, ones that have been found in the air and deposited on the ground after this and other accidents, include some 18 radionuclides with highly variable half-lives (half-life being the time it takes for half of the substance in question to disintegrate). Table 1 shows the six of these that can play significant roles in food contamination, together with their half-lives in days or years.

The principal radionuclides of concern regarding food contamination after nuclear accidents have been iodine 131 in the short run and 137Cs, as well as 134Cs

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iodine 131*</td>
<td>8.05 days</td>
</tr>
<tr>
<td>Strontium 88</td>
<td>52.7 days</td>
</tr>
<tr>
<td>Cesium 134</td>
<td>767 days (≈ 2 years)</td>
</tr>
<tr>
<td>Strontium 90</td>
<td>27.7 years</td>
</tr>
<tr>
<td>Cesium 137*</td>
<td>30.1 years</td>
</tr>
<tr>
<td>Plutonium 239</td>
<td>24,400 years</td>
</tr>
</tbody>
</table>

*Principal contaminants from the Chernobyl accident.

Olszyna Maray, Radioactivity and Foods 33
to a lesser degree, in the long run. $^{131}$I decays with a relatively short half-life of eight days and therefore could fall to insignificant levels in foods within two months of a single incident. $^{134}$Cs and $^{137}$Cs have much longer half-lives (2 and 30 years, respectively), and so they can continue posing problems for much longer periods.

The path of exposure to $^{131}$I is principally through milk, but one can also be exposed through other foods and inhalation. The most immediate effect of the Chernobyl explosion was increased contamination, especially of milk and fresh leafy vegetables, with this radionuclide.

Iodine is absorbed by the thyroid gland, and small children typically receive higher doses than adults, partly because they consume more fresh milk and partly because the iodine is retained in a smaller organ in children, thus concentrating the radionuclide and producing a higher dose of radiation in a small area. (It should be noted that the radiation dose received in any given part of the body is the energy absorbed per unit mass of tissue.)

Saturation of the body with iodine interferes with additional absorption of this element, and so interferes with entrance of radioactive iodine into the thyroid if this remedy is taken before the radioactive iodine is inhaled or ingested. For this reason, the first preventive measure taken by the health authorities in the Soviet Ukraine and in Poland (the closest neighboring country, which was affected most by the accident) was distribution of potassium iodide tablets to the children. In fact, Polish radio announcements about the distribution of iodine tablets to children provided the first notice to most Soviet citizens indicating that anything worrisome had occurred, since the Soviet authorities did not admit the Chernobyl accident had happened until 28 April, more than 48 hours after the explosion.

Deposition of radioactive material on the ground in late April and early May led to direct contamination of leafy vegetables and pastures (see Table 2). Some 10–20% of the material deposited wet stayed on the plants. Even vegetables in greenhouses and under plastic cover were significantly contaminated by deposits of $^{131}$I at up to 1,000 becquerels (Bq) per kilogram in regions with high airborne $^{131}$I concentrations. (One becquerel equals one disintegration per second.) However, the crop contamination varied greatly between southern and northern Russia and the Baltic states. By early May, the contamination of leafy vegetables, pastures, and cereals was no longer detectable in most regions of the Soviet Ukraine. By mid-June, the contamination of fresh water and rainwater had also decreased, as had the contamination of milk and other dairy products.

Table 2. Principal foods contaminated by the Chernobyl accident and countries or regions imposing restrictions on consumption.

<table>
<thead>
<tr>
<th>Foods</th>
<th>Prohibitions or restrictions on consumption in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leafy vegetables (lettuce, endive), fruits (strawberries, cherries), pastures</td>
<td>Soviet Ukraine, Germany (Bavaria, Berlin), Hungary, Yugoslavia, Switzerland, Poland</td>
</tr>
<tr>
<td>Cereals</td>
<td>Soviet Ukraine, Poland</td>
</tr>
<tr>
<td>Milk</td>
<td>USSR, Poland, Sweden, Finland, Federal Rep. of Germany, Switzerland</td>
</tr>
<tr>
<td>Ice cream</td>
<td>Soviet Ukraine</td>
</tr>
<tr>
<td>Beef</td>
<td>Poland, Switzerland</td>
</tr>
<tr>
<td>Lamb</td>
<td>United Kingdom (Scotland, Cumbria, Cornwall)</td>
</tr>
<tr>
<td>Game meat (deer, rabbits)</td>
<td>Switzerland</td>
</tr>
<tr>
<td>Reindeer meat</td>
<td>Swedish and Norwegian (not Finnish) Lapland</td>
</tr>
<tr>
<td>Fresh-water fish</td>
<td>Austria</td>
</tr>
<tr>
<td>Rainwater</td>
<td>Switzerland, United Kingdom (Scotland, Wales)</td>
</tr>
</tbody>
</table>

34 Bulletin of PAHO 25(1), 1991
northern Europe in accordance with different harvest seasons. In the Scandinavian countries, including Finland, direct contamination of vegetables was not significant because of the relatively late growing season. In central and southern Europe, the highest $^{131}I$ values were found in leafy vegetables (greens) during the first days of May. After that, over the following weeks, the $^{131}I$ concentration fell quickly, the combined result of radioactive degradation and rapid plant growth. Because of the short half-life of $^{131}I$, absorption by the roots was insignificant.

The potential concentration of $^{131}I$ in milk followed a pattern similar to the pastureland contamination. Many farmers kept their cattle indoors to reduce contamination from the pasture, but direct inhalation still contributed to a small amount of $^{131}I$ absorption.

Regarding long-term deposition problems, the dominant one has been posed by $^{137}Cs$. The worldwide contamination by radioactive fission products resulting from explosion of nuclear arms in the air, principally between 1956 and 1962, has been studied in depth. The most important radionuclide in terms of public exposure from this source is known to be $^{137}Cs$, which has a long half-life (approximately 30 years), is easily transported through different food chains, and exposes man both externally from the air and from deposits on the soil and internally after ingestion of contaminated common foods such as milk, meats, and cereals.

Following the Chernobyl accident, abnormally high levels of $^{137}Cs$ were found in the air and in material deposited on the soil, indicating that it was discharged from the reactor as easily as $^{131}I$.

In May and June the $^{137}Cs$ and $^{131}I$ situations were fairly similar. Contaminated leafy vegetables and pastures showed about the same ratio of $^{137}Cs$ to $^{131}I$ as did the initial radioactive precipitation. However, as time passed radioactive contaminants found their way into growing plants by two routes. Much of the direct precipitation on the leaves was absorbed and partly transported to the plants’ fruit and seeds. Another route, from the soil through the plants’ roots, is of less importance the first year; hence, very low levels of radioactivity were detected in plants that sprouted after the initial period of deposition, even in areas where deposition levels had been high. In general, the fruits of plants whose flowers had been contaminated by direct deposition showed $^{137}Cs$ activity levels far higher than those found for plants that absorbed contamination solely through their roots.

As a general principle, it should be noted that the significance of the direct versus the indirect route depends on when in the agricultural season the contamination occurs.

A significant increase in the contamination of cow’s milk was observed a short time after the accident. Levels up to 600 Bq/l were recorded in highly exposed regions. At the end of five weeks, the concentration of $^{137}Cs$ in milk generally declined to less than 100 Bq/l, and it was hoped that this trend would continue through the pasturing season. Toward autumn, the levels increased again when the cows were fed silage or hay that had been contaminated in the month of May, before being stored.

The same considerations apply to meat, but a number of additional factors should be noted. The pharmacologic elimination period of $^{137}Cs$ is longer in muscular tissue than in milk, and therefore the concentration in meat declines more slowly. Nevertheless, contamination of forage components will have to be taken into account when estimating the concentrations of $^{137}Cs$ in animal products. In areas exposed to significant
amounts of $^{137}\text{Cs}$ by the Chernobyl accident, beef and pork from animals fed indoors with grain, silage, or hay showed relatively low $^{137}\text{Cs}$ concentrations (0–40 Bq/kg), while the meat from pasture-fed livestock showed much higher values (200–1,100 Bq/kg) at the end of May 1986.

Special consideration should be given to game meat (notably deer, rabbits, and reindeer). These animals showed much higher levels of $^{137}\text{Cs}$ following the Chernobyl accident than did domesticated animals. Reindeer constitute a special case because the concentration of $^{137}\text{Cs}$ in their food (lichens, berries, and fish) was very high.

Only the southern parts of the regions where reindeer are raised in Sweden and Norway were contaminated. Concentrations of $^{137}\text{Cs}$ equivalent to several thousand becquerels per kilogram of reindeer meat were recorded in the highly exposed regions of those countries. In those regions, the economy of some 15,000 nomadic Laps, based almost exclusively on raising reindeer, was practically ruined, and consumption of reindeer meat from those regions was prohibited.

In contrast, during the author's visit to Finland in July 1988, reindeer steaks were on the menus in most restaurants and packages of smoked, salted, or dried reindeer meat were being sold in all the supermarkets. This was particularly noteworthy because Finland is a country where food, and especially radioactivity in food since Chernobyl, has been very strictly controlled.

Another meat-related economic activity that was strongly affected was sheep-raising in Great Britain—in the regions of Scotland, Cornwall, and Cumbria. Thousands of sheep were destroyed and the sale of their meat prohibited because pastures in these regions were contaminated with $^{137}\text{Cs}$.

Finally, in areas where there was relatively heavy deposition of radioactive material in fresh water with few nutrients (for example, in Austria), the concentration of $^{137}\text{Cs}$ in fish increased significantly (equalling or exceeding 1,000 Bq/kg). However, at markets selling fish taken from the sea or estuaries, levels of contamination in the fish remained much lower (Table 2).

**Actions by International Organizations after Chernobyl**

Before the Chernobyl accident various international organizations had worked to establish reference guidelines for handling environmental contamination with radioactive substances emanating from natural sources, nuclear arms tests, and accidents. Nevertheless, after Chernobyl it was recognized that the available guidelines did not adequately cover actions needed to protect the population in areas at some distance from the source or sources of contamination—especially in the case of accidents at nuclear power plants. As a result, during the period following the Chernobyl accident a number of international meetings were held to help determine how the existing deficiencies could be remedied (Table 3).

The World Health Organization Regional Office for Europe (WHO/EURO), coordinating WHO efforts relating to the Chernobyl accident, organized an emergency consultation at its headquarters in Copenhagen on 6 May 1986, just a few days after the first information on the accident became available. The assembled experts did not try to draw any conclusions about the accident's long-term impact, because at the time detailed information on the extent and geographic distribution of $^{137}\text{Cs}$ deposition was not available. They therefore recommended that this should be the subject of a future study (9). Nevertheless, the Regional Office also began to serve as a clearing-
Table 3. International meetings relating to the effects of Chernobyl.

<table>
<thead>
<tr>
<th>Organization</th>
<th>Place</th>
<th>Dates</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO/EUROa</td>
<td>Copenhagen</td>
<td>6 May 1986</td>
<td>Chernobyl reactor accident</td>
</tr>
<tr>
<td>WHO/EURO</td>
<td>Bilthoven</td>
<td>25-27 June 1986</td>
<td>Estimation of radiation dosage received in Europe</td>
</tr>
<tr>
<td>IAEAb</td>
<td>Vienna</td>
<td>24 July 1986</td>
<td>Detection of radionuclides</td>
</tr>
<tr>
<td>FAOc</td>
<td>Rome</td>
<td>1-5 December 1986</td>
<td>Limits on radioactive contamination of foods</td>
</tr>
<tr>
<td>CCFAd</td>
<td>The Hague</td>
<td>17-23 March 1987</td>
<td>Radioactive contamination of foods</td>
</tr>
<tr>
<td>WHO</td>
<td>Geneva</td>
<td>6-9 April and 21-25 September 1987</td>
<td>Derived intervention levels for radionuclides in foods</td>
</tr>
<tr>
<td>EECe</td>
<td>Brussels</td>
<td>5 May and 1 July 1987</td>
<td>Consequences of the Chernobyl nuclear accident</td>
</tr>
<tr>
<td>CCFA</td>
<td>The Hague</td>
<td>7-12 March 1988</td>
<td>New developments with respect to contamination of foods with radionuclides and other subjects</td>
</tr>
</tbody>
</table>

*aWorld Health Organization Regional Office for Europe.
*bInternational Atomic Energy Agency.
*cFood and Agriculture Organization of the United Nations.
*dCodex Alimentarius Committee on Food Additives.
*eEuropean Economic Community.

...house for information on radiation levels and public health actions taken by the European countries. This information was widely circulated, first biweekly and later on a weekly basis, during the entire emergency period.

In addition, WHO/EURO followed up on the Copenhagen meeting's recommendation by convoking a working group of experts in the fields of radiation medicine, agriculture, foods, health physics, meteorology, and public health, together with representatives of international and intergovernmental organizations, to make a preliminary assessment of the impact of the Chernobyl accident on Europe. This meeting, held in Bilthoven, the Netherlands, on 25-27 June 1986, was organized in collaboration with two WHO centers, the Institute of Radiation Hygiene of the Federal Office of Health in Neuherberg, Federal Republic of Germany, and the National Institute of Public Health and Environmental Sanitation in Bilthoven.

On the basis of available measurements, meteorologic data, and appropriate predictive models, the participants reviewed the extent of radionuclide deposition. They also estimated the nature and extent of food contamination, and made tentative predictions about the effects of doses associated with different paths of exposure, based on information obtained in various countries. In this connection it was noted that the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) intended to prepare a more complete and detailed review of the long-term consequences, which was to become available in 1988.

In sum, the group determined that there was a need to consult at the international level regarding collection of samples, methods used to report results, and the composition of specific food "baskets" in different geographic regions in order to facilitate estimation of the exposure caused by ingestion of contaminated foods. It also emphasized the need to develop international guidelines based on these data regarding levels of food contamination justifying intervention.

As a result of discussions held during the Thirty-ninth World Health Assembly and comments made at the special session of the Conference of Governors of the International Atomic Energy Agency (IAEA) on 21 May 1986, the group also produced a preliminary text citing the need to improve the exchange of infor-
mation and the emergency measures that should be taken in Europe in the event of important nuclear accidents (10).

In addition, during the days after Chernobyl the United Nations Food and Agriculture Organization (FAO) received queries from various member governments about actions to be taken regarding radioactive food contamination. In response, it convened an Expert Consultation on Recommended Limits for Radionuclide Contamination of Foods that was held in Rome on 1-5 December 1986.

This group noted that one of the problems emerging after the Chernobyl accident was the simultaneous use, by various organizations and experts, of different units to describe measurements of such things as "radioactivity" and "absorbed dose." Specifically, regarding food contamination by radionuclides, it recommended using only units and terms of the Système International (SI). Within that system the unit of radioactivity is the becquerel (Bq). The "equivalent dose," represented by the symbol $H_T$, is the dose absorbed modified by the quality factor and any other factors that can influence the biologic effect of the radiation according to its nature (e.g., alpha or beta radiation). The unit in this case is the sievert (Sv), which equals one joule per kilogram (100 rems in the old terminology). As indicated in Table 4, other basic units and symbols are derived from these two.

The group recommended that provisional international intervention levels be adopted to govern radionuclide-contaminated foods in international commerce. The levels recommended were based on primary intervention levels for public protection in the event of accidental escape of nuclear material, levels previously established by the International Commission on Radiologic Protection (ICRP) (12).

In the absence of other guidelines, FAO proposed that the levels recommended by the Expert Consultation be applied to international food shipments, and that the levels applicable to international trade be considered separately from the intervention limits necessary to protect consumers who live near where a nuclear accident has occurred or where a high level of contamination is present (13).

Subsequently, in collaboration with other international organizations, WHO proposed establishing what it called "derived intervention levels for radionuclides in foods." These would be levels of radioactivity in foods below which there is no justification to intervene.

In calculating these levels, the WHO experts took careful account of available data on consumption patterns of various classes of foods in approximately 140 countries and areas, consumption patterns grouped into eight regional types.

Table 4. International units recommended for use in dealing with cases of radioactive contamination.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Symbol</th>
<th>Equivalence</th>
<th>Measure of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Becquerel</td>
<td>Bq</td>
<td>One disintegration per second</td>
<td>Radioactivity</td>
</tr>
<tr>
<td>Sievert</td>
<td>Sv</td>
<td>1 joule/kg (= 100 rems)</td>
<td>Equivalent dose absorbed</td>
</tr>
<tr>
<td>Becquerels per kilogram</td>
<td>Bq/kg</td>
<td>Radioactive contamination of food</td>
<td></td>
</tr>
<tr>
<td>Sieverts per becquerel</td>
<td>Sv/Bq</td>
<td>Dose per unit of absorption</td>
<td></td>
</tr>
</tbody>
</table>

1 rem = 1 roentgen equivalent man = the dosage of an ionizing radiation that will cause the same biological effect as one roentgen of gamma or X rays. (A roentgen is the amount of gamma or X radiation producing ionization equal to one electrostatic unit of charge in one cubic centimeter of dry air at 0°C and standard atmospheric pressure.)

Dose absorbed modified by the quality factor (for example, susceptibility of the organ) and any other factors that can influence the biological efficacy of the radiation in accordance with its character (for example, the limited penetrating power of alpha or beta radiation).
(African, Central American, Chinese, Eastern Mediterranean, European, Far Eastern, North African, and South American). These data had been compiled by FAO but had apparently not been considered in its own report. WHO also used estimates proposed by FAO for average per capita consumption of food (550 kg per year) and drinking water (700 liters per year) (14).

Other noteworthy early actions included a series of meetings on the Chernobyl accident's consequences that were held on 1 July 1986, 24 October 1986, and 1 July 1987 by the Economic and Social Committee of the European Economic Community (EEC). These resulted in a proposed subcommittee "opinion" on Chernobyl that was adopted by the committee at its last plenary meeting. Although these meetings were mainly concerned with safe production of nuclear power, a recommendation was made that the Commission of the European Community establish maximum acceptable levels of radioactivity in foods (11).

CONCLUSIONS

As noted earlier, it may seem odd to combine two subjects as different as use of ionizing irradiation to preserve foods and measures needed to protect foods from ionizing radiation. However, both issues relate to the same power unleashed in this century—the power of atomic energy. Furthermore, once people unleashed this power they had a two-pronged problem: how to use atomic energy to humanity's advantage, to improve and perhaps prolong life, and at the same time how to protect humanity, so as to avoid both nuclear war and lesser kinds of nuclear devastation.

Effective response to this challenge, besides requiring that we improve our knowledge of the situation and soundly apply intelligence and common sense, needs international collaboration and a full and open exchange of information. Fortunately, the surprisingly detailed early report on Chernobyl that the Soviet Government presented to the International Atomic Energy Agency and divulged to the world (after the instinctive reflex of absolute silence for the first two days) gives grounds for believing that in the era of glasnost the effects of a similar catastrophe (which one hopes will never happen) might now be handled more effectively and with less confusion and fear than was the accident at Chernobyl.

REFERENCES

2. Becker RLA. A determination of the radioactivity induced in foods as a result of irradiation by electrons of energy between 10 and 16 MeV. US Army Natick Research and Development Command; April 1979; contract number DAAK60-78-R-0007.
New Advocacy Organization Focuses on Child Survival

The majority of the 14 million child deaths that occur every year could be prevented with existing low-cost techniques of proven effectiveness, such as immunization and oral rehydration therapy. With this in mind, heads of State from 71 countries, meeting at the historic World Summit for Children in October 1990, agreed on 22 measurable child survival goals for the year 2000. In order to turn this promising rhetoric into reality, the Alliance for Child Survival was founded to encourage citizen activism.

The Alliance works to mobilize health care professionals to express their concerns for the health status of children in developing countries. Its purpose is to empower and coordinate nurses, doctors, dentists, pharmacists, and others in educating the public and convincing key legislators in the United States Congress to increase funding for international child survival efforts. The Alliance is developing a network of advocacy groups in key congressional districts throughout the U.S.; it does not employ professional lobbyists.

For more information, contact Chuck Woolery, Director of Organizing, Alliance for Child Survival, 315 Dean Drive, Suite 100, Rockville, MD 20851-1144, USA; phone or fax (301) 738-7122.