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Possible Effects of Nuclear Radiation Accidents on Agriculture

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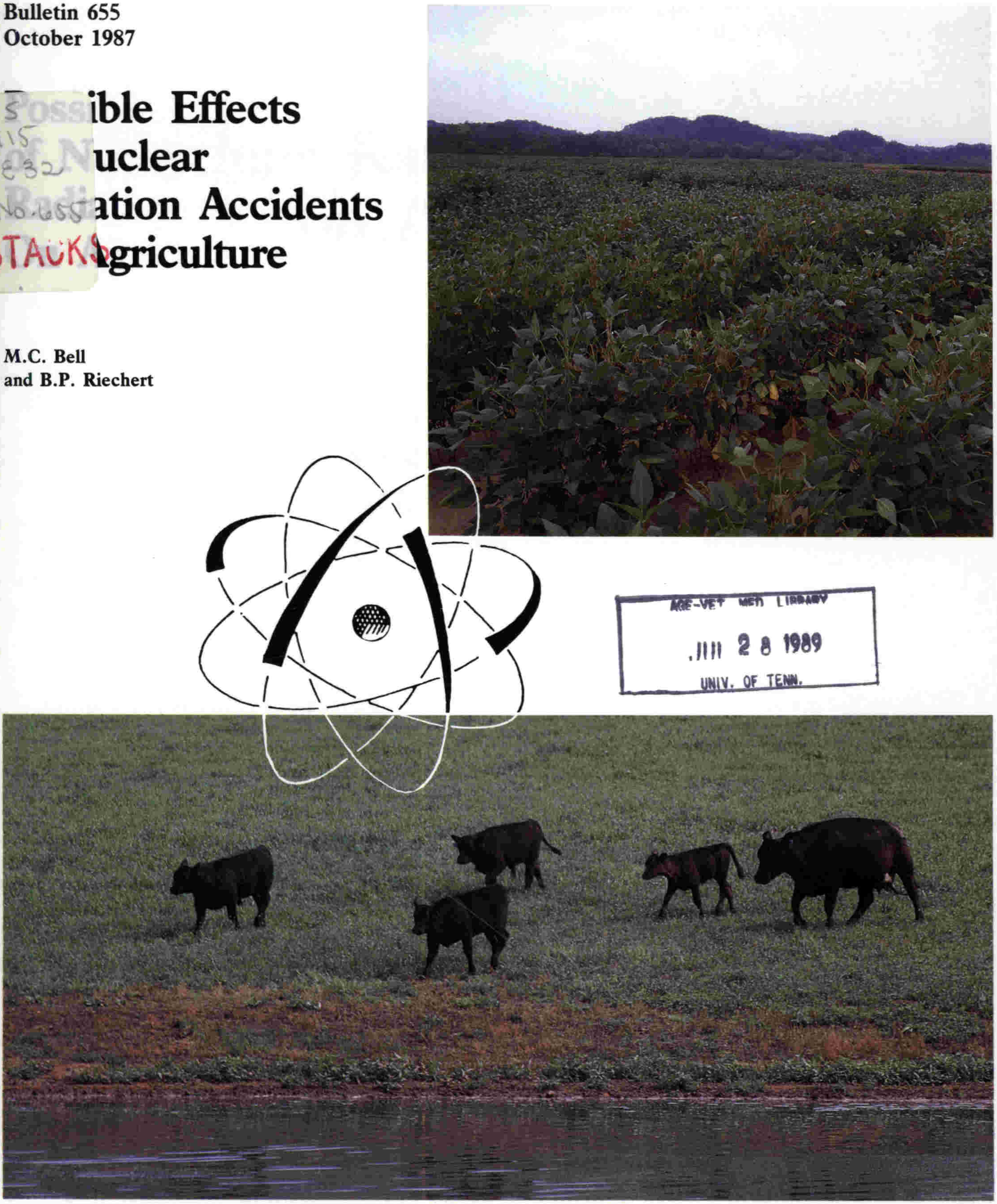

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Possible Effects of Nuclear Radiation Accidents on Agriculture

M. C. Bell[1] and B. P. Riechert[2]

Introduction

The purposes of this report are (1) to assess the impact of nuclear radiation accidents on agriculture using power reactor accidents as the primary concern; (2) to place nuclear radiation risks into proper perspective with other risks; and (3) to propose plans of action for the agricultural industry if Protective Action Guides are exceeded.

Consequences of nuclear war on agriculture are not considered in this report since they are so different, severe, and devastating in comparison with peaceful uses of this valuable energy resource. This report will focus on: (1) history of nuclear radiation accidents, including reactors, nuclear weapons tests, and nuclear accidents; (2) possible radioactive contamination; (3) possible food chain contamination; (4) recommended action for reducing food contamination; (5) radiation induced cancers; and (6) risks from exposure to ionizing radiation. A glossary of terms is provided at the end of the publication.

Not only is nuclear fission a source for heat to produce steam to turn turbines to produce electricity, but the fission products are useful for many purposes. The fission products are used in medicine, food and grain preservation, and to provide power for remote installations on earth and in outer space.

Production of food and fiber in the United States now depends upon advanced technology and involves less than four percent of the population. Many people are also involved in agricultural-related industries, such as food processing, transportation, and marketing. Over 75 percent of the population in many of the developing countries are involved in food and fiber production. Most developing countries do not produce sufficient food for their own use, while the United States exports a surplus of more than half of its food grains to pay for expensive imports such as oil. Some of this country's surplus is also used as gifts to feed starving people throughout the world. Continued viable agriculture will require a continuous supply of energy from available sources.

Of primary importance is continued production, relatively free of risk, of food for humans. Degree of risk should be considered in relation to the other risks in life. Both food and energy are needed wherever people are located. In fact, over 75 percent of the United States' total milk cows are located in states with one or more operating nuclear power reactors (Bell and Bell 1981 and Halsey 1980c). This report will focus on contamination of milk because milk is the primary route of radionuclide contamination in the food chain to humans. Radionuclide contamination of the agricultural food chain may come from accidents that may involve reactor fuels, fuel reprocessing and storage plants, and transportation of radioactive materials. Improper use of radiation facilities and sources that are designed for both medical and industrial uses have been responsible for accidental radiation exposures.

Per cent consumption of all dairy products in the United States was 594 pounds milk equivalent in 1986 (Miller and Short 1987). Most dairy farms meeting this demand are located near the greatest population centers.

Nuclear power reactors are currently providing about 16% of the electrical energy demand in the U.S. Much inconsistent, misleading, and sensationalized information has been published about the risks of nuclear power reactors. Simon (1980) suggested that inaccurate statements may be made and circulated for a number of reasons. These include selling of books, newspapers, magazines, obtaining of funds for research efforts, and striving for an unrealistic, idealistic, and utopian state of affairs. Many journalists are not well informed or educated on the processes involved in nuclear power generation (Garvey 1987). Nuclear power is not an energy alternative to be discarded because of emotional hysteria. It should be considered along with other options based on risks and

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costs. The consequences of not having nuclear power reactors are cited rarely in the popular media. Conservative estimates put energy cost increases at 50%.

History of Nuclear Radiation Accidents

Reactors

Windscale Atomic Pile No. 1 - October 10, 1957. The earliest notable nuclear radiation accident occurred when inadequate instrumentation for maintenance operations and poor judgment on the part of the operating staff combined to cause an overheating accident at the No. 1 atomic pile of a plutonium-producing facility at Windscale, England, (Bishop 1959; Bell and Bell 1981).

According to the readings on dosimeter badges for the 13-week period that included the accident, only 14 workers directly associated with the accident were exposed to more than the maximum permissible levels of radiation. The International Commission on Radiation Protection (ICRP) permissible level for 13 weeks was then 3.0 R. The highest figure measured from the workers' badges was 4.66 R (Bell and Bell 1981).

Public concern mounted, and precautions were taken to ensure uncontaminated food supplies. Milk supplies in the area were condemned for human consumption if samples showed 0.1 µCi/liter of radioiodine (Chamberlain and Dunster 1958; Bell and Bell 1981). Milk distribution was under restriction for two to five weeks in the coastal area near the accident, an area about 30 miles long, 10 miles wide at one end and six at the other end (Bell and Bell 1981; Ward 1961). Other foods and sources in the area were checked for possible contamination and found to be not harmful; thus no restrictions were placed on any of these (Bell and Bell 1981; Chamberlain and Dunster 1958).

In the official report to the British Parliament, officials stated, "We can justifiably say that it is in the highest degree unlikely that any harm has been done to the health of anybody in the course of this accident," (Bell and Bell 1981).

Vinca, Yugoslavia - October 15, 1958. An accident at Vinca, a suburb of Belgrade, occured at a "zeropower" reactor built for experimental purposes (Savic 1959). This accident involved a brief uncontrolled run at the assembly which went undetected because of the lack of an interlock system and the fact that the safety circuits and monitors were turned off.

At the time of supercriticality, eight persons in the immediate area around the reactor vessel were exposed to very large doses of neutrons and ionizing radiation. Total body radiation exposures measured 300 - 1500 R. An exposure of 400 to 500 R is considered lethal in 50 percent of the people exposed. The doses received by the Yugoslavian workers were very high, averaging 683 rems. One person died, and the seven others were treated and apparently suffered no complications. According to reports, no radioactive material escaped the facility, so there was no impact on the food chain (Bell and Bell 1981).

Three Mile Island, Goldsboro, PA - March 28, 1979. The highly publicized accident at Three Mile Island (TMI) number two reactor resulted from a series of equipment malfunctions complicated by human misjudgments. The story of TMI has been told and retold, but the actual series of events culminating in the worst nuclear accident this country has seen may never be fully understood due to the many different interpretations of the accident.

Three Mile Island reactor,completed in December 1978, was a pressurized water reactor that could produce 880 megawatts of power. The accident apparently started when a turbine trip caused a pressure-relief valve to vent nonradioactive steam into the outside atmosphere on the morning of March 28, 1979. The events following were termed a general emergency, but made up a general state of confusion as well. Part of the confusion resulted from the lack of a unified authority for such an emergency. On the scene were representatives of various government agencies, state regulators, and assorted media personnel. Reports were handed down from Pennsylvania governor's office, the Nuclear Regulatory Commission's crisis response center, the Pennsylvania Department of Environmental Resources, Metropolitan Edison (who operated the plant), Nuclear Reactor Regulation (a division of NRC), Pennsylvania Emergency Management Agency, and various other groups. This gave citizens in the surrounding areas virtually no real center of authority for obtaining recommendations during the crisis time.

Equipment failures and operator errors resulted in coolant levels in the pressure vessel falling below the top of the core, causing serious overheating. Claims abounded that the core would melt down, expelling radioactive materials onto the surrounding area. Further reports concluded that even if the core had melted down, it "would probably solidify before it melted through the TMI concrete foundation, and even if it didn't, the bedrock underneath would be an effective block" (Burnett 1980). If a meltdown occurred, the fissionable material would be more dispersed, reducing the fission rate, and in turn, reducing the temperature.

As it happened, the core was severely damaged but did not melt down. Radioactive xenon-133 and krypton-85, noble gases that are not retained in the human body, were released from TMI. About 15 Ci of radioactive iodine were released into the atmosphere. "The health effects of this iodine were insignificant" (Burnett 1980). Samples taken at 375 kilometers of the air mass containing gas released from the TMI plant showed that the "whole-body dose to an individual . . . was 0.004 mrem." This amount is small indeed in comparison to background radiation from natural sources, which is annually over 100 mrem or about 25,000 times the level from TMI (Wahlen et al. 1980).

More than 100 dairy farms were located within 50 miles of the TMI plant. A total of 8,490 dairy cattle, 1,880 beef cattle, 475 swine, 100 sheep, 70 horses and 18 goats were reported on 100 farms surveyed by the Pennsylvania Department of Agriculture in May following the accident (Halsey 1980b). About 630,000 people lived within a 20-mile radius of the plant.

Testing of milk for iodine-131 was started the day of the accident, and tests were conducted on 50 dairy farms within 35 miles of the plant. Sampling was done by the Pennsylvania Department of Agriculture's Division of Milk Sanitation. Two gallons of milk were taken from each dairy for testing by the Bureau of Radiation Protection and by the Food and Drug Administration. Milk was also checked at 26 dairy processors (Halsey 1980a).

Early milk tests showed insignificant amounts of radioisotopes. Final testing of the fresh milk revealed a range from 0.67 to 1.52 Bq/l (Halsey 1980a). This amount was significantly below the 444 Bq/l at which milk is considered unsafe to drink and the 14.8 Bq/l in Pennsylvania as a result of the 1976 China tests (Krieg 1979).

Precautionary measures were taken to prevent contamination. Farmers were advised to put their animals in barns and give stored feed, although most cows were still in barns from winter (Krieg 1979). The stored feed would not have been contaminated by effluents from TMI. [Testing of vegetables and soil samples revealed no traces of radioisotopes by TMI (Krieg)].

The editor of *Dairy Herd Management* magazine surveyed its readers in the seven-county area surrounding TMI, and found that only one percent of the respondents reported having moved their cows to another location during the height of the crisis. Ninety-three percent of the respondents said they had not considered moving their cows. Only one percent of the dairy producers reported dumping any milk because of the accident (Halsey 1980b). Although the milk was considered safe to drink, some consumers in neighboring states were wary of milk products from the TMI area. Grocery stores put up signs advertising their milk came from other areas, and sales of bottled water to concerned consumers increased. The news media carried many comments exaggerating the recent events. Of farmers surveyed in the area, 69 percent said they believed that the media overplayed the incident, and 68 precent said that they thought their milk sales were hurt by the TMI plant shutdown (Halsey 1980b).

Bill Fouse, head of the Pennsylvania Division of Milk Sanitation, who was in charge of inspection and quality assurance during the accident, summed up the attitude of many farmers toward the TMI accident and the energy situation as a whole with this statement: "I think the farmer will probably think more rationally than any other segment of society" (Halsey 1980a).

The special Kemeny Commission concluded that, in spite of the serious damage to the TMI plant, the actual release of radioactivity would have a negligible effect on individuals. Mental stress was the main effect.

Chernobyl - April 26, 1986. The worst nuclear power reactor accident observed in the world to date started in the early morning hours on Saturday, April 26, 1986, at the Chernobyl plant near Kiev, USSR (Figure 1). Unit four at the power station was involved in an experiment, during which a sudden surge of power was followed by two explosions in rapid succession. This steam explosion was caused by a sequence of operator errors, including the unauthorized disconnection of several safety systems. The force of the explosion blew the metal top off the reactor, dislodged the huge crane above the reactor, and probably ruptured all of the 1659 cooling water tubes (Abagyan et al. 1986). The blasts of the steam explosions were so severe that they created a chimney effect and propelled fission products high into the atmosphere. The 6-foot-thick side walls held, and increased the "chimney effect." A fire broke out, melting some of the asphalt floors and roofs. Four hours later, two workers had died and several workers suffered thermal burns, excess radiation exposures, and other injuries. One body was not recovered. The accident was thought to be under control.

With the loss of water coolant to the fuel rods and possible other damage, radioactivity continued to be released into the atmosphere. Then the graphite, which was used as a moderator in that type of reactor, caught on fire, and the radioactive releases into the atmosphere increased in a later explosion (Figure 2). The early release appeared to be mostly radioactive volatiles such as iodine, cesium and the inert noble gasses. Later, fragments of nonvolatile particles were released into the atmosphere, including radioisotopes of strontium, barium, uranium, and plutonium. It is estimated that about half of the radioactivity in the reactor was released into the atmosphere. This amounted to about 6 million times as much radioactivity as was released from TMI in 1979 (Norman 1986 and Norman and Dickson 1986). Maddox (1986) estimates about 100 MCi of radioactivity was released, with half of it in the gaseous form. USSR estimates are given in Table 1.

The first public announcement regarding the accident from the USSR came only after Sweden officals detected the radioactive contamination coming from the USSR. This was followed by media and government speculation, rumors and sensationalism throughout the world. Speculations about large losses of life may have been fueled by the amount of radioactivity found in Scandanavia, which seemed to indicate a massive reactor accident. The chimney effect that pushed the released radioactivity high into the atmosphere was not considered in probable scenarios. USSR officials offered little information about the accident, but instead criticized the so-called exaggerations from the western governments and media. Soviet Leader Gorbachev even suggested establishment of an international panel to set up guidelines to ensure notification of neighboring nations in the event of a nuclear accident. This was not a new suggestion. The IAEA panel of 1967, with representatives of 15 nations, including Mr. Koslov of USSR, published a 1969 Safety Series No. 32 pamphlet on "Planning for the Handling of Radiation Accidents." The pamphlet did exactly what Mr. Gorbachev requested, but USSR officials ignored the guidelines (Henningsen et al. 1969). The Chernobyl accident spread radioactivity over a larger area but caused less loss of life than the 1957-58 USSR fuel reprocessing accident (Trabalka et al. 1980).

Evacuation of 90,000 people around Chernobyl was initiated 36 hours following the accident. During the next 10 days,

FIGURE 1
LOCATION OF CHERNOBYL NUCLEAR POWER STATION IN USSR

(Abagyan 1986)

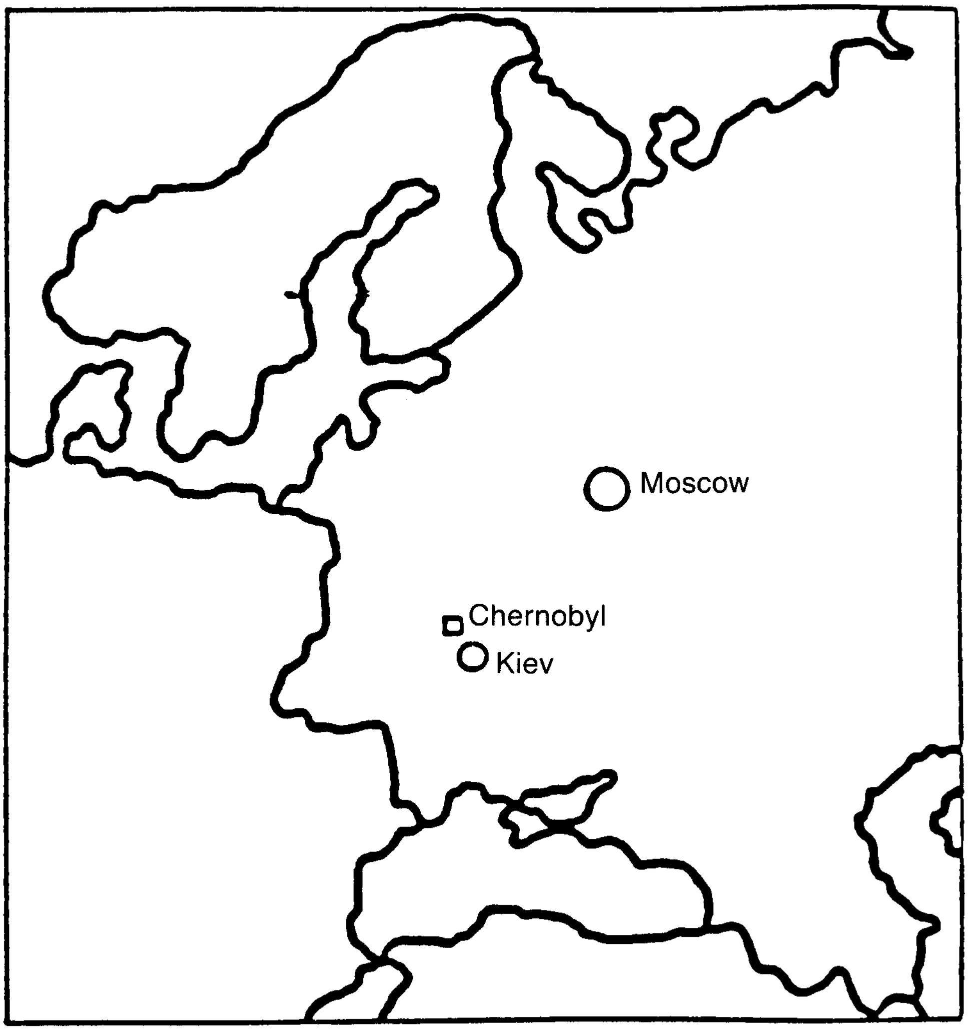


Table 1

Daily Radioactive Releases into the Atmosphere from the Accident Unit (Without Radioactive Noble Gases)*

(Abagyan 1986)

Date	Time After the Accident, Days	Q MCI**
26.04	0	12
27.04	1	4.0
28.04	2	3.4
29.04	3	2.6
30.04	4	2.0
01.05	5	2.0
02.05	6	4.0
03.05	7	5.0
04.05	8	7.0
05.05	9	8.0
06.05	10	0.1
09.05	14	0.01
23.05	28	0.002

*Estimated error -50_X

**values are recalculated for May 6, 1986 taking into account the radioactive decay

a total of 135,000 were evacuated. This orderly evacuation may have been delayed until release activity rate had been reduced to a safer level. Loss of life was relatively small for the scope of this accident. Two workers died from mechanical and radiation injury in the first few days. Radiation sickness combined with thermal burns resulted in additional deaths over the next several weeks. Thermal burns and injury reduced the chance of survival from near lethal radiation injury. These reported observations agree with animal research data (Bell 1971). Some 16 weeks after the Chernobyl accident, fewer than 30 related deaths had been reported by USSR officials.

Soviet officials did not disclose any effects on agriculture from the accident until late August 1986 in the IAEA conference in Vienna. Since the chimney effect would be expected to take the radioactivity high into the atmosphere, the local effect on agriculture was probably very small. However, one report estimates that 50% of the released radioactivity was deposited within 30 km of Chernobyl. The accident occurred on the west edge of Ukraine agricultural production area. The air currents following the accidents carried most of the radioactive fallout northwest and west of the food producing areas of USSR and then on to adjacent countries. From the German data (Hohenemser et al. 1986), we would expect hot spot effects in the USSR where some of these radioactive particles are retained on plants and animals. These would probably not result in deaths of animals or entire plants, but would probably result in noticeable local effects like those reported from fallout on livestock at NTS (Nevada Test Site) and Alamogordo, N.M. (Bell 1985). Effects would vary, depending on the particle size, amount of radioactivity, and time of particle retention. In animals, these effects might vary from no noticeable effect to graying of hair to sores and scar tissue in the injured area. Since all the human deaths and fatalities were among the workers and firefighters in the reactor building, radiation levels in the agricultural areas would be expected to be much less due to dispersal and dilution of the released radioactivity.

Abagyan et al. (1986) reported that no effects on plants and animals were observed beyond the 30-km zone around the facility. Radioactive contamination varied within the 30-km zone, but there was some effect on radiosensitive plants. Although results from most soil samples were not yet available, one soil sample taken on May 6, 1986, 1.5 km from the power plant, contained 1.2 X 10^7 Bq/g. They also stated that soil uptake by plants was of no significance in crops harvested before August 1986.

Iodine-131 concentration in milk varied greatly as shown in Figure 3. Highest levels of about 80 μCi/l were observed in Byelorussia, which is more sparsely populated than the Ukraine. The range was from about 0.01 to 80 μCi/l for iodine-131 in this area (Abagyan et al. 1986). The USSR maximum permitted level of 0.1 μCi of iodine-131/l was exceeded in all of the 11 areas reported in Table 2. These data in Table 2 demonstrate that milk was the only food product in which radioactivity exceeded the permitted regulatory level in all 11 areas. Iodine-131 was the major radioactive contaminant in milk.

Cesium isotopes were the principle radioactive contaminants in meat. Meat exceeded permitted levels in four areas; berries and greens in three areas; vegetables in two areas; and fish in only one area. Meat samples contained 0.1 to 0.02 μCi/kg of radioactive cesium. These data demonstrate the importance of monitoring milk even though the range of radioiodine concentrations varied widely (Figure 3). Data were also presented in Vienna showing that on the first day of the accident thyroid iodine-131 was monitored in 171 persons. Most of the people had less than 20 μCi/ thyroid, but one individual had over 200 μCi. Presumbably the iodine-131 came from inhalation and skin absorption.

Data on the amount of each radioactive isotope released are presented in Table 3. Little radioactivity was reported in soils and forages. Levels of 11 radioisotopes in clover near Chernobyl (Table 4) one month after the accident were not high, and radioisotopes of cesium were of lower concentration than the other radioisotopes measured.

The effects of Chernobyl accident on personnel responsible for the agricultural food chain outside of USSR were quick and very dramatic. Poland distributed iodine tablets which were taken to block iodine-131 thyroid uptake from contaminated food. Large quantities of lettuce and fresh vegetables were destroyed in Germany, even though most of the contamination levels were low (Personal communication, Diehl 1986, and Pfau 1986). Canada refused to accept fresh vegetables from Italy due to detectable fallout. The British government condemned lambs due to the levels of radioactive cesium. On May 7, 1986, U.S. task force personnel refined and updated Protective Action Guides (PAGs) levels that had been established in 1982 (Nature 1986). In the U.S., prices

FIGURE 2

ACTIVITY AND TEMPERATURE OF THE FUEL AFTER THE ACCIDENT

(Abagyan 1986)

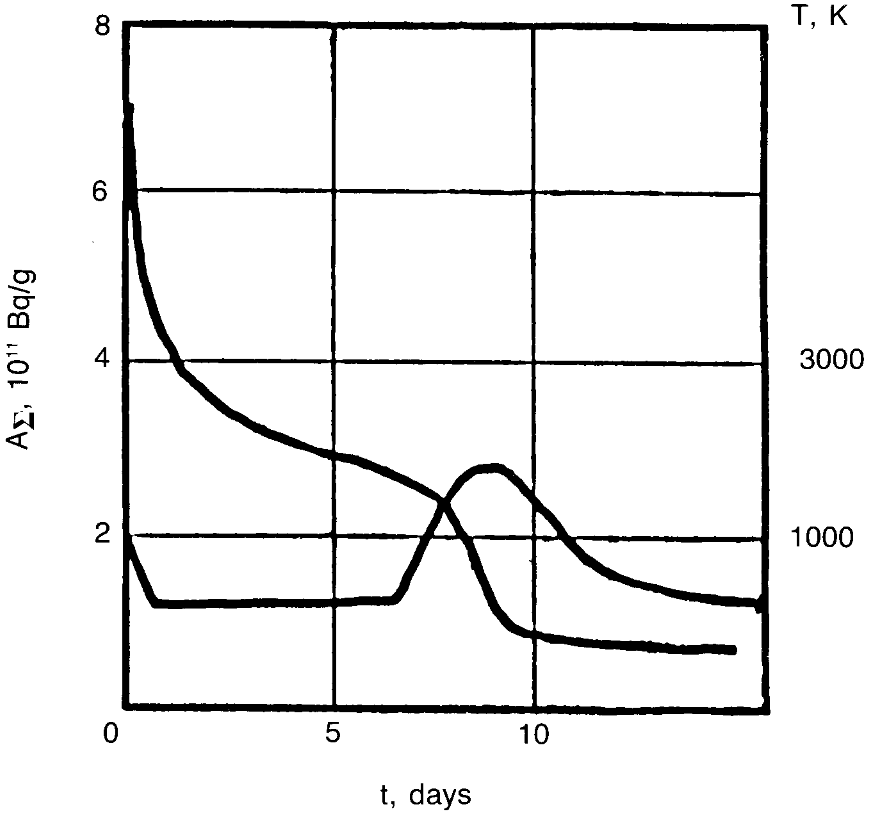


Table 2
Agricultural Products in which the Permitted Radioactive Contamination was Found to be Exceeded

(Abagyan et al. 1986)

Republic	Region	Food Products which do not comply with regulations					
		Meat	Milk & Dairy Produce	Greens	Vege-tables	Berries	Fish
Byelorussia	Minskaya	10	5	—	—	—	—
	Gomelskaya	40	30	15	10	5	90
	Brestakaya	10	50	5	3	5	—
	Mogilewskaya	20	10	—	—	—	—
	Grodhenskaya	—	5	—	—	—	—
RSFSR	Tulskaya	—	15	—	—	—	—
	Bryanskaya	—	30	—	—	—	—
	Kalujskaya	—	20	—	—	—	—
	Kurskaya	—	30	—	—	—	—
	Oriovskaya	—	10	—	—	—	—
The Ukraine	Kievskaya	—	10	20	—	20	—

for wheat and bakery products abruptly increased by 20%, but were back to the pre-Chernobyl levels by four weeks after the accident.

Levels of iodine-131 in milk were reported for samples collected by British Embassy personnel in several Eastern Block countries. They are summarized in Table 5, adapted from Webb et al. (1986) and other authors. These data show the large variation in iodine-131 in these locations. Radioactive contamination of milk was also monitored in several other countries. In the vicinity of Munich, Germany, milk levels of radioactivity were highest May 3, following the highest forage levels on May 2. At this time, iodine-131 levels exceeded cesium-137 levels by a factor of 5. By the end of May, iodine-131 decayed to the point that cesium-137 exceeded iodine-131 by a factor of almost 5. Only very small quantities of strontium-90 were measured in the ground, amounting to about 10% of the level measured during weapons testing (1954-1966), but there was four times as much cesium-137 found after Chernobyl than in weapons test fallout (GSF - Bericht 1986). These data confirm that primarily volatile elements were released from Chernobyl. Other data in this report show the distribution of radioactive fission products deposited and incorporated into the food chain. Short-lived molybdenum-99 is absorbed and excreted quickly by humans and swine. Tellerium-132 is also short-lived and most of it is not absorbed into the body. Cesium and strontium are long-lived, and almost 100 times more cesium than strontium was deposited. The radioisotopes of Ru were intermediate in abundance and in half life (40 d and 1 y). Fortunately, Ru is very poorly absorbed by animals, with absorption amounting to less than 1% of intake (Thompson et al. 1958). For long term planning purposes, it is expected that cesium-137 will be the only fission product that needs consideration outside of USSR.

Table 3
Estimated Releases of Radionuclides from the Accident at Chernobyl Nuclear Station (Ch NPS)*

Nuclide	Released Activity, MCI		Release Percentage by 06.05.86
	26.04.86	06.05.86**	
Xe-123	5	45	may be up to 100
Kr-85m	0.15	--	–"–
Kr-85	--	0.9	–"–
I-131	4.5	7.3	20
Te-132	4	1.3	15
Cs-134	0.15	0.5	10
Cs-137	0.3	1	13
Mo-99	0.45	3	2.3
Zr-95	0.45	3.8	3.2
Ru-103	0.8	3.2	2.9
Ru-106	0.2	1.6	2.9
Ba-140	0.5	4.3	5.6
Ce-141	0.4	2.8	2.3
Ce-144	0.45	2.4	2.8
Pu-238	0.1E-3	0.8E-3	3.0
Pu-239	0.1E-3	0.7E-3	3.0
Pu-240	0.2E-3	1E-3	3.0
Pu-241	0.02	0.14	3.0
Pu-242	0.3E-6	2E-6	3.0
Cm-242	0.3E-2	2.1E-2	3.0
Sr-89	0.25	2.2	4.0
Sr-90	0.015	0.22	4.0
Np-239	2.7	1.2	3.2

*Estimated error ±50%

**Total release by May 6, 1986,

(Abagyan et al. 1986)

FIGURE 3
I—131 CONCENTRATIONS IN COW MILK

(µCI/L)

(Abagyan et al. 1986)

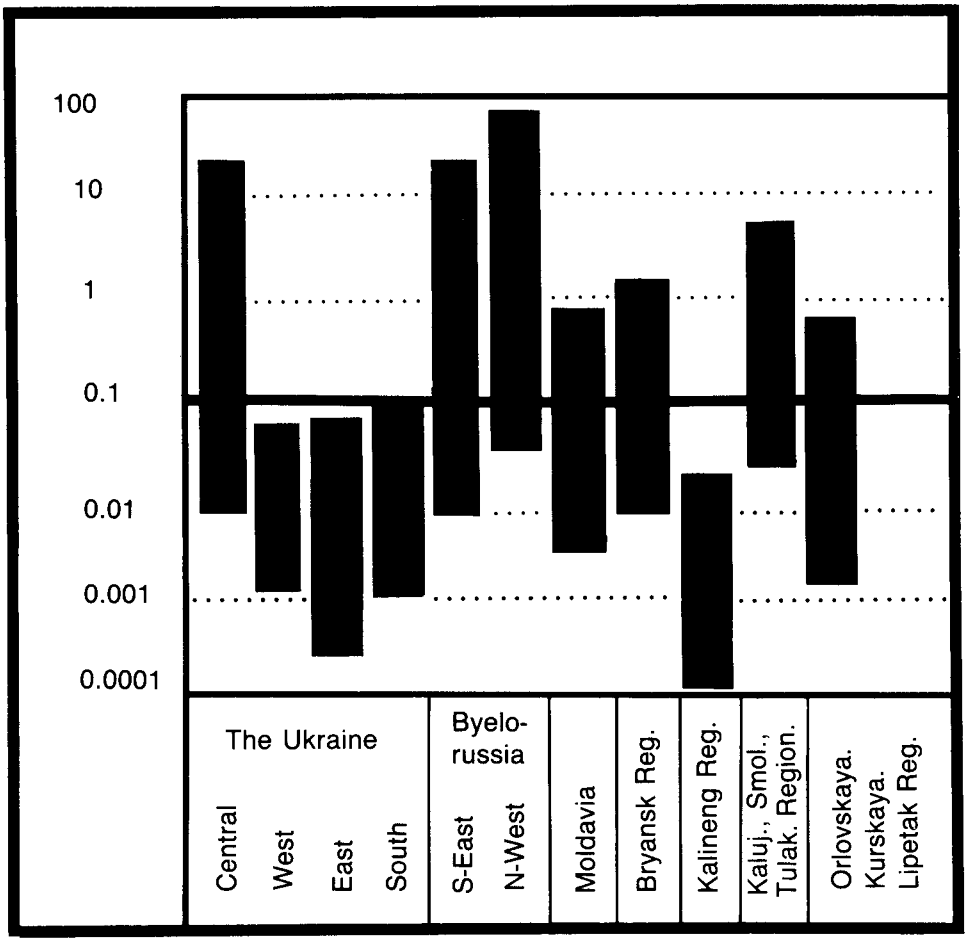


Table 4
Radionuclide Content in Clover at Chernobyl Near Ch NPS On 26 May 1986.

Nuclide	Content µCi/kg
Ce-144	2.0
Ce-141	1.4
I-131	1.3
Ru-103	1.2
Ru-106	0.79
Ba-140	0.67
Cs-134	0.32
Cs-137	0.25
Zr-95	1.5
Nb-95	2.0
La-140	0.53

(Abagyan et al., 1986)

Abagyan et al. (1986) data reported in Vienna demonstrated the high levels of food contamination near Chernobyl nuclear power plant (Table 5). Variation of radioactivity levels in USSR and other countries was very great. Moscow showed 15-18 Bq/l of iodine-131 in milk compared with 370 - 3,000,000 Bq/l in Byleorussia. Some information from the August 1986 IAEA meeting indicated a concern that plant uptake of cesium in the low humus soils found in part of the fallout area may be higher than in other soils. Speculation is great due to release of little hard data. Normal agricultural practices in cultivated farm land will increase the chance of binding most of the cesium to soil particles, especially in clay soils. Less binding of cesium is encountered in sandy soils. Data by Handl and Pfau (1986) and Ward and Johnson (1986) show lower uptake of fallout cesium deposited on plants compared with $CsCl_2$ used in most research studies.

Table 5
Levels of Radioactive Fallout from Chernobyl Nuclear Accident

	Milk Bq/l	Meat Bq/Kg	Forage Bq/Kg	Water Bq/l
131_{I}	15-18[a] 50-150[b] 20-2000[c] 100-500[d] 16-2600[e] 420[f] 1500[g] 370-3,000,000[h] 370-740,000[i] 37-3,700[j] 1,100[o]	700[r]	15,000[g] 48,000[k] 370,000[q]	10-10,000[l]
137_{Cs}	9,300[k] 5-500[l] 200[g] 300[o]	21-48[m] 300-2,000[r] 300-10,000[s]	4,000[r]	20-20,000[l] 700[m] 10-10,000[l]
134_{Cs}	10,000[k] 2-200[l]	19-30[n] 4,000[p]		
132_{Te}	5-50[l]			10-10,000[l]
132_{I}				7,400[l]
Mixed Radioisotopes			4,000[b]	

a-f. Webb et al. (1986): a-Moscow, b-Yugoslavia, c-Poland, d-Czechoslovakia, e-Hungary, f-Rumania.
g. Handl and Pfau (1986) Germany
h-k. Abagyan et al. (1986): h-Byleorussia, i-Central Ukraine, j-South Ukraine, k-Chernobyl
l. Clark (1986) U.K.
m. Thomas and Martin (1986) France
n. Jones et al. (1986) U.K.
o. GSF-Bericht (1986) W. Germany
p. Phelps (1986) U.K.
q-s. Goldman et al. (1987): q-USSR, r-West Germany, s-Sweden

Radioactive contamination of travelers in USSR was demonstrated in both British and Japanese personnel. British students were recalled from USSR since radioactivity in the Scandinavian countries indicated a release significantly greater than from the British Windscale accident. Travelers from Moscow showed no radioactive iodine contamination of the thyroid while the 99 people traveling near Minsk and Kiev all had measureable levels of radioiodine in their thyroids. Considerable variation was observed, but all these measured less than 30% of British annual limit for thyroid dose to the public. Most of the radioactivity was on the student's clothing, but only 2% of the clothing exceeded the "clearance" level. Since Minsk is about 300 km north of Chernobyl and Kiev about 100 km south, absorption of radioiodine in those locations demonstrates the magnitude of the accident (Holliday et al. 1986). Changes in the external radiation exposure rate due to decay are shown in Figure 4. In addition, the total estimated exposures and doses in the 30-km area around Chernobyl are given in Table 6 showing that the public exposure was well below the lethal levels for humans.

Nuclear Weapons Tests - 1945-1962

For a number of years, the United States and USSR tested nuclear weapons on and above the surface of the earth. Although a test ban treaty for ground testing was signed by representatives from several countries, other countries have tested weapons. Some of these were surface bursts (detonated at ground level) and others were air bursts. Other than medical uses of ionizing radiation, most experience with high levels of radiation has been with radioactive fallout resulting from nuclear weapons tests during the 1950's and 1960's.

Alamogordo - 1945. The first atomic bomb was exploded at Alamogordo, New Mexico on July 16, 1945. This explosion produced visible effects on 130 cattle out of a herd of 300 Herefords that accidently wandered on to the bombing range. This tower shot incorporated soil, the tower and other debris in the radioactive fallout, causing damage to the backs of some of these cattle. Fallout retention was probably increased by the moisture on the hair of the cattle from a thunderstorm that occurred several hours before the detonation. None of these cattle died from radiation injury, but the ranchers noted sores on the backs and some hair and skin losses 2 to 4 weeks after exposure. In December 1945, sixty of the most severely affected cows were shipped to Oak Ridge, Tennessee, for security and research purposes. In 1948, through a contract with the Atomic Energy Commission, the University of Tennessee established an Agricultural Research Laboratory (UT-AEC-ARL) to study radiation effects on these cattle and other animals and plants, including fission product metabolism. These cattle showed effects on their backs varying from graying of red hair, to hyperkeratosis, epilation, and horn like growths. Fourteen years after exposure, squameous cell carcinoma developed on the backs of three of the most severely affected cows.

Productivity of the exposed cows was comparable to productivity of 70 control cows brought from New Mexico in 1948. One of the exposed cows produced normal calves every year she was under observation from 1948 through 1961 and was pregnant at the time of her death on October 4, 1962 (Bell, 1985 and Figure 5).

NTS — 1953. On March 24, 1953, a fallout cloud from Nevada Test Site (NTS) passed over the rangeland north of NTS in Nevada and Utah. Some owners reported unusually high death losses in ewes and lambs grazing in the area and suspected radioactive fallout as the cause of death.

Estimated losses were 3,000 lambs and 2,000 ewes amounting to 20-25% of the lambs and 20% of the ewes. Estimated total body dose was 2.6 rad, with higher levels coming from

Table 6

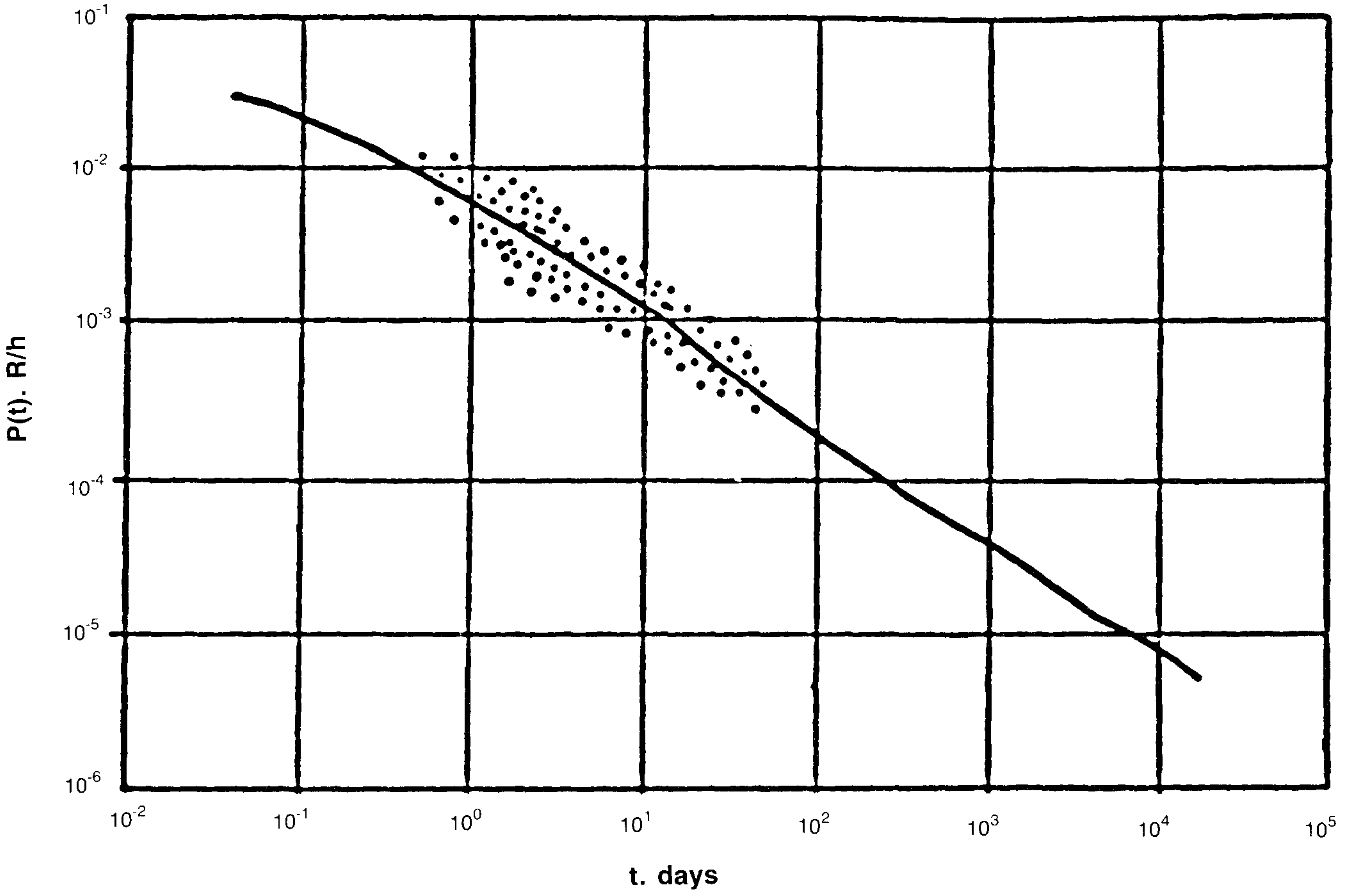
Estimated Doses of Public Exposure in Some Populated Areas in the 30-km Zone Around Ch NPS

(Abagyan et al. 1986)

Settlement	Distance from ChNPS km	Exposure from discharge cloud	Dose on child's thyroid rem	Dose from Radioactive fallout in 7 days R	
				Estimate	Actual
Chistowka	5.5	10	120	8.4	3.2
Levlev	9	7	250	17	10
Chernobyl	16	1.2	80	5.6	3.0
Rudkl	22	0.6	80	5.6	2.2
Crevichi	29	0.2	25	1.8	4.4

Figure 4
Change of the γ-radiation dose rate in the open country on the Ch NPS radioactive release trace.

(Abagyan et al. 1986)



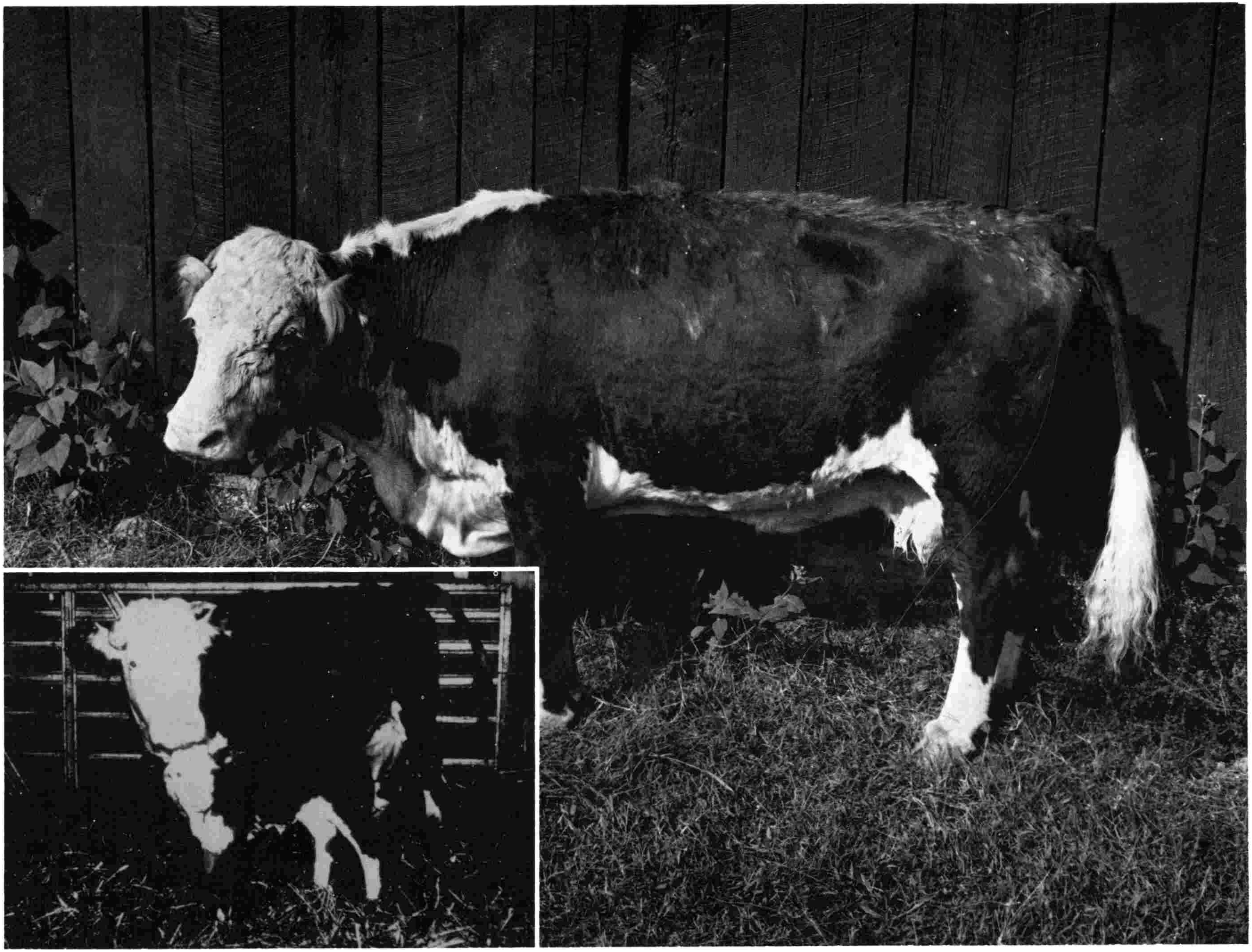


FIGURE 5: Hereford cow accidentally exposed to fallout on July 16, 1945, at Alamogordo, New Mexico. Note Grey hair on back and side. This cow produced 15 calves in 16 years at UT-AEC- ARL. Calf at side in insert.

ingested radioactivity on the forage. Tissue doses were estimated to be highest for thyroid, followed by rumen wall where insoluble fallout particles might accumulate. Experimental research suggests that these dose levels would not be expected to have any measurable effect on the sheep health or survival (Sasser et al. 1971).

During the time of the sheep deaths, this area suffered one of the worst droughts on record, with rainfall at only 50% of the normal level. Reduced available forage may have resulted in animals consuming toxic plants. Final conclusions were that the sheep deaths were not a result of exposure to radioactive fallout (Sasser et al. 1982). No record was found for any observed fallout effects on the forage. At worst one might find local "burns" from the Beta activity in fallout particles retained on the surface of plants.

From 1951 to 1959, 88 burros were exposed to 180 - 545 R in research at NTS and in Oak Ridge compared with 24 controls. The irradiated burros survived for about 12% fewer years than did the controls. In March 1987, only one control burro and one burro exposed to about 250R at NTS were still alive (Figure 6 Lushbaugh et al. 1983).

Pacific Tests - 1954. The United States did some of its nuclear weapons testing on small, uninhabited islands in the Pacific Ocean and some accidental exposures occurred. Some accidental exposures to residents occurred on the Marshall Islands on March 1, 1954, when the wind direction shifted unexpectedly and carried "significant amounts of fallout" to the islands of Rongelap, Alginare, and Utirik. The whole body gamma radiation exposures ranged from 175 R on Rongelap, to 69 R on Alginare, to 14 R on Utirik (Sutow et al. 1965).

None of the residents on Utirik developed radiation symptoms, but the residents of the other two islands showed signs and later showed some latent effects of their exposure. Other than cesium-137 in coconuts, records of agricultural effects were not found.

Nuclear Accidents

Cheliabinsk Province USSR - Winter 1957-1958. Reports indicate a tremendous accident occurred in the Soviet Union involving the atmospheric release of fission wastes and resulting in contamination of a large area about 800 miles east of Moscow, although USSR officials have not to date confirmed these reports to the world. Trabalka et al. (1980) reported that the accident involved huge quantities of nitrates exploding in a nuclear waste storage and separation facility. An estimated 100 to 1000 km^2 area was contaminated and hundreds of deaths occurred. Volatilization of fission products was probably at a minimum from the nitrate explosion(s). Much of the cesium-137 was thought to have already been removed before the explosion, so that the principal long-term contaminant was strontium-90 (10^5 - 10^6 Ci). From 10^8 to 10^9 Ci of total fission products were initially released. About 30 villages previously shown no longer appear on maps of the area. Paths of streams and the size of some lakes in the area have also been changed.

Data on radiation effects from this accident on agricultural plants and animals have not been released by USSR officials. Neither have data been released on the amounts of contamination of the food chain. However, published experimental data from USSR since the accident may have relevance to the accident. Osanov et al. (1974) reported on a dosimeter model for dairy cows using 1.75 Ci of soluble mixed fission products per cow. This was probably related to levels ingested by cattle from the waste accident and not related to early fallout from a surface nuclear explosion, which was modeled in animal experiments using insoluble ^{90}Y labeled sand (Bell et al. 1970).

FIGURE 6: Mexican burros in 1987. One control (52) and one irradiated (38) are only survivors of experiment started in the early 50's.

US - Mexican Cobalt-60 Contamination - December 1983. Improper disposal of 1003 Ci of cobalt-60 in a teletherapy unit from a hospital in Texas resulted in near lethal levels of severe radiation injury to a Mexican family and others. The unit was sent to a Specialists Medical Center in Mexico where it was stored for 6 years. It was then junked and the sealed cobalt source was broken open, releasing many tiny (1 mm) cobalt pellets. The unit was placed into a pickup truck, exposing a Mexican child and his family. The child played with pellets in the truck. Other pellets were strewn along a 100 mile area into Mexico as the salvaged unit was moved to a metal processing plant. Some of the cobalt-60 was returned to U.S. in steel reinforcing rods and metal tables made from molten steel contaminated with some of the cobalt-60. No evidence has been found for this contamination entering the food chain or having any effect on agriculture, but it is an example of what can happen when people do not follow prescribed safety procedures for disposal of highly radioactive materials (NRC 1986).

Uranium Conversion Plant - January 4, 1986. At the Sequoyah Fuels Corporation in Gore, Oklahoma, the contents of a full 14-ton UF_6 tank were accidently released into the atmosphere. The uranium hexafluoride quickly changed into UO_2F_2 and HF upon contact with the air. Two herds of cattle, consisting of 99 steers and 87 heifers, were downwind from, and adjacent to, the facility. These cattle averaged about 600 lbs. and were feeding on improved pasture plus hay. On January 6, the cattle were removed from pasture, penned, and fed hay. Urine sampling of some of these cattle plus control animals from either 10 miles west or northwest of the plant, was initiated and continued through May 1986. Animals belonging to the public were also examined, and urine samples from the cattle were analyzed for uranium and fluoride. Uranium and fluoride toxicity is primarily a chemical toxicity concern because uranium is not very radioactive.

Uranium levels in urine were about 1600 µg/l for heifers and 470 µg/l for steers on January 6. By the middle of February, levels had declined to 6 to 9 µg/l. Urine samples from public owned animals averaged about 6 µg/l while the controls on improved pasture had urine samples averaging 16 µg/l. Phosphate fertilizer probably contributed the extra uranium found in the control animals on improved pasture. The UO_2F_2 is probably one of the most available forms of uranium even though usually less than 1% of ingested uranium is absorbed by animals.

Fluoride was also abundant in the soil and in livestock feeds. Levels were about 6 times as much as controls, and amounts in urine were about 6 mg/l for exposed and 1 mg/l for controls. Ingested fluoride is much more readily absorbed than ingested uranium. Levels are in mg for fluoride and µg for uranium indicating danger from fluoride toxicity was greater than for uranium.

Retention of both uranium and fluoride was considered to be insignificant and of no consequence in these livestock (Still, 1986 personal communication).

Possible Radioactive Contamination

Sources

It is very important, in discussing radiation, to remember that radioactivity is not a new phenomenon. Naturally-occuring radioactivity can be found in the earth's crust, building materials, food, drinking water, space, people, and animals (Lenihan et al., 1967). For thousands of years, all life on earth has been exposed to radiation from cosmic rays and radioactive elements. Man, too, has developed in an environment of different levels of natural radiation found throughout the world.

In Southwest France, the natural dose from two natural uranium isotopes exceeds 100 rad (Leonard et al. 1979). This area in southern France and an adjacient area in northern Italy are known for health spas that advertise the curative powers of mud and waters that are high in alpha-emitting radioactive material.

Some areas of the United States are also naturally high in radiation. For example, the background dose is estimated at 130 - 230 millirem per person per year in Denver, CO, compared to 80 - 105 millirem for the whole country. In addition to this background radiation, other sources contribute to total yearly dosage. Diagnostic and therapeutic medical treatments add an average of another 70 millirems to the total per person per year (EPA 1977; Bondansky 1980).

If the number of nuclear power plants in this country were greatly expanded, the additional average dose above background and all other sources would only be about one millirem per person per year (Bodansky 1980), about 1% of the average natural background. At present, the amounts of radiation received from nuclear power plants under normal conditions is less than that received from the radionuclides emitted from coal-fired power plants. In fact, a preliminary study by the Environmental Protection Agency rated coal up to 80 times riskier than nuclear power reactors in terms of the radionuclides given off during normal operation (Agres 1980). The study suggested that there are "greater risks to the public of developing cancer from radionuclides emitted by coal-fired power plants than by normally operating nuclear plants" (Agres 1980).

Coal naturally contains very small amounts of U-238, U-235, Th-232 and their radioactive daughters (McBride et al. 1978), along with sulfur, iron, and moisture (Agres 1980). As coal is burned, most of the mineral content is turned to ash and slag. These waste forms contain most of the radionuclides, but small amounts escape into the atmosphere. These amounts depend upon the "particulate control system, furnace design, mineral content of the coal, and the existing emission control standards" (Agres 1980). As more new scrubbing systems are put into use, the amounts of escaping particulate matter are expected to decrease. However, the present figures for fatalities from coal are higher than those for nuclear power (Bodansky 1980). This comparison is not intended to incriminate coal for its very small amount of radioactivity, but merely to demonstrate that nuclear power plants are not the only sources of radioactivity.

Coal from different parts of the country contains various levels of radionuclides. Coal types from all parts of the United States average one part per million for uranium and two ppm for thorium (McBride et al. 1978). Some coals were 10 to 40 times higher in concentration than the averages; anthracite from Pennsylvania was the highest in thorium, and lignite from the Gulf States - Alabama, Arkansas and Mississippi - was the highest in uranium (McBride et al. 1978). All uranium and thorium, regardless of source, are radioactive. Both of these elements occur in several isotope forms and their radiation emissions vary in intensity, form and energy.

In view of these facts, the role of nuclear energy industry must be considered in relation to other risks incurred in everyday life. Nuclear power itself has not only been shown to be useful, it can also pose hazards. The question of radiation is not just one of concern with nuclear power plants; it deals also with natural background, coal fired power plants, medical X-rays, radiation treatments, jet flights, cardiac pacemakers, watches, smoke detectors, artificial teeth, and nuclear explosions (Haaland 1979).

Experimental procedures have shown varying effects of radiation on animals. The estimate given for the median lethal dose for man is "300-500 rads for short-term total-body radiation" (Hamilton 1963). A similar lethal dose (LD 50) applies to animals as well (Bell 1971). Animal data is much more extensive, and some of it was obtained from animals at Nevada Test Site.

Low Level Radiation Effects

The natural radiation levels in southwest France in excess of 100 rads per year were studied. Researchers found that an annual dose of 70 rads of gamma rays per year to rabbits caused small increases in chromosome abberrations in the blood lymphocytes, while they observed "no effect on the spermatozoa of male mice similarly exposed, nor on their offspring" (Leonard et al. 1979). From these and similar studies, it appears that chromosome abberrations are not indicative of measurable damage to germ plasm, which would result in effects on offspring.

Extensive studies were conducted at the Los Alamos Scientific Laboratory with 44 generations of male mice. These studies "failed to reveal any genetic effects from large gonadal radiation doses." This line of mice received a total dose of 8,800 rads over the 44-generation period with "no demonstrable damage" reported. As compared with the controls, the irradiated mice showed no substantial differences in reproductive life and overall life span, among other factors. Conclusions drawn from this study indicate that mutations in sperm may have in fact been induced, but the deviations were probably fatal to the fertilized eggs (Bell and Bell 1981). Erickson et al. (1976) studied long-term ionizing radiation effects on 280 cows and found that from 6 to 300 R from cobalt-60 had no measurable effect on reproductive performance and no effect on germ cells and follicle counts.

After a five-year study, Shetland ponies irradiated with a cumulative exposure of 650 R of whole-body gamma radiation were found, in general, "able to perform work under the conditions of the experiment as efficiently as the non-irradiated ponies" (Brown 1975). Numerous other studies have been conducted dealing with effects of high and low levels of radiation. Since "risk may be looked upon as the probability of the occurrence of some unfavorable event" (Wodicka 1980), the risk of operation of a nuclear reactor power plant must be considered in relation to other risks encountered in everyday life.

Nuclear Reactor Accidents

Four general classifications of nuclear power reactor accidents are defined by the Nuclear Regulatory Commission: notification of unusual event, alert, site emergency, and general (Table 7). Two types of possible accidents of concern from the public standpoint are loss of coolant accidents (LOCA) and fuel meltdown.

"It now seems probable that the worst possible accident from the point of view of the exposure of the public to ionizing radiation is not a runaway nuclear reaction, but a loss of coolant accident," suggested researcher Richard Wilson in 1973. He explained that the accident could happen if the cooling system in the reactor vessel or steam piping failed in most commercial power reactors. Even though the nuclear reaction would stop as soon as the moderator (the coolant) disappeared, heat would continue to be produced, leaving the core uncooled, unprotected and with the possibility of meltdown (Wilson 1973).

The question of nuclear explosions in power reactors should be of little concern. This was emphasized in 1969 by Dr. Karl Z. Morgan, then director of Health Physics Division of Oak Ridge National Laboratory, who said, "At this point, I would like to make it very clear that nuclear explosions (weapons type) are impossible in nuclear power reactors" (Morgan 1969). Nuclear reactors are designed to prevent explosions like an atomic bomb (Kemeny 1979). The fuel in commercial reactors is not highly enriched (contains less fissionable uranium) and is configured for a sustained reaction, not an explosive burst.

The Kemeny report concluded that at TMI the hydrogen bubble inside the pressure vessel could not have exploded or ruptured the pressure vessel (Burnett 1980).

Possible Food Chain Contamination

Livestock play an important link in the human food chain by supplying nutrients, using sources of nutrients that humans cannot directly use, and filtering out many undesirable materials from the diet. Cattle and sheep depend mostly on hay and pasture in their diets, while swine and poultry depend mostly on grain.

Iodine

Iodine, essential to the thyroid gland function, is usually present in the thyroid equal to the amount in the diet (Miller et al. 1975). Feeding excess iodine, however, increases iodine excretion with some increase in thyroid iodine. Iodine losses from normal intake include 30% feces, 40% urine, and 8% in milk. (Dairy cows secrete less iodine in milk than most other species.)

Cows' milk has different concentrations of iodine at different stages of lactation, with a higher concentration in the later stages. However, a mixed herd of cows will be at different stages, and this difference will not play an important part in the level of radioiodine in the milk. Even after secretion into the mammary gland, much of the iodine is available for resorption (Miller et al. 1975).

Radioisotopes of iodine, predominately iodine-131, would be the main concern from a nuclear reactor. Contaminated fresh milk is the main contributor of iodine-131 to the human diet. Inhalation of iodine-131 and consumption of unwashed, contaminated vegetables and fruits would not be expected to be a significant problem. In the case of commercially produced fruits and vegetables, the transit time from harvest to consumer is long enough for large amounts of the isotope to decay. Milk, on the other hand, is of major concern, if the dairy cows are consuming contaminated pasture, because of its short market time.

Table 7

Classification of Nuclear Power Reactor Accidents (Grimes and Ryan 1980)

Class	Class Description	Release Potential	Expected Frequency
Class 1: Notification of an unusual event	Unusual events are in process or have occurred which indicate a potential degradation of the level of safety of the plant.	No releases of radioactive material requiring offsite response or monitoring are expected unless further degradation of safety systems occurs.	Once or twice per year per unit.
Class 2: Alert	Events are in process or have occurred which involve an actual or potential substantial degradation of the level of safety of the plant.	Limited releases of up to 10 Ci of I-131 equivalent or up to 10^4 Ci of Xe-133 equivalent.	Once in 10 to 100 years per units.
Class 3: Site emergency	Events are in process or have occurred which involve actual or likely major failures of plant functions needed for protection of the public.	Releases of up to 100 Ci of I-131 equivalent or up to 10^6 Ci of Xe-133 equivalent.	Once in one hundred to once in 5000 years per unit.
Class 4: General emergency	Events are in process or have occurred which involve actual or imminent substantial core degradation or melting with potential for loss of containment integrity.	Releases of more than 1000 Ci of I-131 equivalent or more than 10^6 Ci of Xe-133 equivalent.	Less than once in about 5000 years per unit. Life threatening doses offsite (within 10 miles) once in about 100,000 years per unit.

The peak concentration of iodine-131 from a single dose occurs about one day after the intake. If cows are allowed to remain on contaminated pasture, the peak level will be reached in three days (Comar 1965). Still, the amount that is passed on in milk is less than the cow received. "Under conditions of oral ingestion, about 8% of the daily intake of iodine-131 is secreted into each day's milk" (Comar 1965).

The physical half-life of iodine-131 is eight days, but experimental work showed that on undisturbed pasture, the biological half-life may vary from three to six days (Sasser and Hawley 1966). Reduction of the iodine-131 on the pasture can occur from radioactive decay, rainfall, wind, mechanical disturbance, or new growth.

Swedish researchers found that of the iodine-131 deposited on pasture area, 60% volatilized before the cows were put on the pasture 18 hours later. While the cows were grazing over the next three days, an additional 6% of the iodine-131 dissappeared; thus, about 2% was eaten by the cows (Auraldsson et al. 1971).

Almost all dairy cows are given supplemental feed even when they are on pasture. Non-lactating cows are usually not given supplemental feed on pasture. However, one must assume that any grazing cow could receive contaminating doses of radioiodine and pass it on in milk.

Radioiodine may get into the cow diet via ingestion of contaminiated pasture, contaminated feed, water, or other means. The exposure from inhalation is considered minimal to zero (Thompson 1967). Once cows are removed from contaminated pasture, the level of contamination in milk will drop rapidly. Water from cisterns or ponds could supply lesser amounts of iodine in the diet.

Exposed cattle may be fed stable iodine to reduce the iodine-131 content in milk. Daily feeding of 1.3 g reduced the level in milk by one-third, while feeding 2.0 g reduced it one-half in a Tennessee study (Miller et al. 1975). Non-lactating cattle contribute insignificant amounts of iodine-131 to the food chain, due to the decay of radioactive iodine during the delay time from grazing of cattle to meat consumption and the small amount of iodine that accumulates in meat.

Radioiodine contamination of fresh vegetables and fruits is less of a problem with commercially-produced food because of the transit time from harvest to market. However, home gardens could contain contaminated foodstuffs from radioactivity deposited on the surface of leafy vegetables. These vegetables, because of their proximity to the consumers, might be eaten within 24-hours after they were contaminated (Thompson 1967). This time period would not allow for sufficient radioactive decay of iodine-131. Direct consumption of iodine-131 in water might be a problem in water from cisterns, but not in that from wells and treated municipal water supplies.

Strontium

Radioisotopes of strontium are a small percentage of fission products. Strontium-90 is of concern in the food chain to humans because it has a long half life of 28 years and because it reacts chemically like calcium. Over 99% of the strontium retained bẏ humans and animals is in the bones. Large amounts of strontium-90 in bone can cause bone cancer. Of the approximately 20% of dietary strontium absorbed, most of this is excreted in urine and feces with some excreted in milk from lactating animals. Young growing animals will absorb more strontium than adults, but will have a faster turnover rate of strontium due to bone growth and bone remodeling. Much has been written on strontium in the food chain to humans (Lenihan et al., 1967). Biological organisms discriminate against strontium-90 in preference for calcium. Strontium-90 can enter plants both by uptake through the roots and by absorption after deposition on plant surfaces. The absorption of the calcium and strontium-90 from soils is influenced by clay content, humus content, pH, moisture level, concentration of electrolytes, and the calcium already in the soil (Comar 1965). Strontium will more likely be taken up by plants growing in soils that have a low level of calcium (Lenihan et al., 1967).

The amount of contamination that a cow passes along in milk will be much less than the amount ingested, because the animal "always puts into milk less of the strontium than the calcium that is in the ration" (Comar 1965). Strontium-89, with a much shorter half-life of 50 days, moves through the food chain like strontium-90, but causes fewer problems because it decays faster.

Cesium

Cesium-137 affects plants by direct contamination, and some can be easily removed from plants by rainfall. Very little of the cesium is taken up from the soil, probably because of the "fixation in the lattice structure of clay minerals." More would be available from sandy soils (Ward 1961). Some fixation of foliar-deposited cesium has been observed in animals fed forage containing fallout cesium compared with radioactive cesium chloride (Ward and Johnson 1986).

Once in an animal's body, cesium-37 is metabolized like potassium and moves through the gastrointestinal tract and on to the muscle tissues. In lactating animals, the cesium passes through to milk, also. As a result, most of the contamination to the human food supply is from milk and meat (Eisenbud 1963).

Plutonium, Krypton, and Xenon

Experiments showed that, following ingestion by a cow of a soluble form of plutonium, less than .000001% of the dose per liter was secreted into milk" (Comar 1965). Practically none of plutonium ingested was absorbed, and 99.99% was excreted in the feces of livestock.

Krypton and xenon are inert gases that are poorly soluble in water and tissues (Sagan 1974). Annual doses of krypton-85 are small and are estimated to continue to remain insignificant. In addition, the importance of cumulative doses in the population is marginal (Eichholz 1976). When released into the atmosphere, those gases mix completely with the air, which already contains one ppm krypton and 0.1 ppm xenon. Both of these inert gases are used in light bulbs; xenon-133 is a radioactive gas used in cardiac, blood flow and pulmonary function studies (Windholz 1976; United Nations 1977). Krypton has a biological half-life of 18 hours; xenon, an average of 7 hours (Sagan 1974).

Recommended Actions to Protect the Food Supply

In the event of a nuclear power reactor accident that releases fission products into the atmosphere, there are appropriate actions that can be taken to help protect the food supply. Emotionalism has no place in the rational response to contamination of our foods. Some recommendations may not apply to everyone, as geographic differences and climatic limitations often dictate actions. Measures to deal with a possible contamination are given, including the Protective Action Guides set up by the federal government (Table 8). Protective Action Guide levels in the U.S. were proposed in 1977, established in 1982 and then slightly revised on May 7, 1986 after the Chernobyl accident. (Schelien et al. 1977; Federal Register 1982; Engel 1986). The USDA Radiological Emergency Response Plan should be consulted for guidance. This plan is being revised and probably will be condensed into a clear and concise set of guidelines for procedures in the near future.

Soil

Soil contamination would not be of immediate concern, but proper management procedures could do a great deal to reduce a problem, should contamination occur. The addition of lime to calcium-poor soils can reduce the uptake of radioactive strontium by plants. Usual soil cultivation practices for row crops would reduce the amount of radioactivity on the surface. Turning the soil by plowing would greatly reduce the surface radioactivity and reduce the plant uptake of radioactivity by diluting the concentrations around the roots. However, it may not be advisable or practical to cultivate pasture areas, especially if erosion would be increased.

Vegetables

The greatest amount of contamination reaches vegetables directly. Rainfall carries radioactive contamination into cavities of the fresh leafy vegetables where it collects. For commercially produced vegetables that have a waiting period between harvest and market, this would not be a problem for short-lived contaminants. Skins or outer leaves of homegrown vegetables should be removed and the remainder washed throughly. Canning, freezing, or other storage of vegetables would allow decay of short-lived radionuclides. Heavily contaminated vegetables might be fed to livestock or discarded.

Grain

For grains, Protective Action Guide action would probably not be needed, but milling and polishing will reduce the amount of contamination. Time from harvest to consumer would be an important factor here, and in many cases, may be several months. Grains have much lower concentrations of calcium and potassium than cereal stems and leaves, so they would also be low in strontium and cesium. Grains are high in starch and low in minerals. Minerals are mostly in the seed coat so milling and polishing would reduce content of fission products. Feeding the seed coat products to livestock would further dilute the fission products in human food.

Milk

Lactating dairy cows currently on pasture should be removed and fed uncontaminated stored feed and water. Silages or other feeds harvested and stored before an accident would be acceptable. Milk should be tested by an appropriate agency, and their advice should be followed if Protective Action Guide levels are exceeded. Possible actions would include diversion of milk for manufacturing purposes or withholding contaminating milk from market to allow for radioactive decay. Milk could be frozen, concentrated, dehydrated, or processed in other methods to allow this to occur. Radionuclides can be removed from milk via ionexchange resin columns; however, to date this process has not been commercially explored on a large scale and is available in only a few areas. The same principles would be involved to protect milk from fallout from nuclear weapons, except weapons contain much higher concentrations of radioactivity and cover much greater areas (Bell and Blake 1976).

Meat

Meat and meat products would be considered on a case-by-case basis, according to the Protective Action Guides. Strontium is concentrated in bone, so bone removal before cooking meat is advisable. Most of the cesium can be removed from meat by extracting water from 1'' cubes of meat (Bell 1985).

Eggs

Eggs contribute only minor amounts of contamination to the food chain and these would not present a problem. Furthermore, chickens are housed in buildings that could provide shielding from most airborne contamination, and their feed likely would have been processed and stored before an accident.

General

If iodine-131 is the only radionuclide that exceeds Protective Action Guides, then storage to allow the iodine to decay would be a solution. Contaminated food products could also be diverted and fed to livestock other than cows producing milk.

Radiation Induced Cancers

Exposure to high levels of ionizing radiation increases the incidence of cancers. Cancers caused by radiation cannot be distinguished from cancers from other causes. In humans,

Table 8

Prevention Protective Action Guides (PAGs)

	Milk Bq/kg	Meat Bq/kg	Forage Bq/kg	Ground Bq/m^{2}	Water Bq/l
131_{I}	555^{a}		$1,850^{a}$	$4,800^{a}$	
	555^{b}		$1,850^{b}$		$4,800^{b}$
	$2,000^{d}$	$1,500^{c}$			$11,000^{d}$
137_{Cs}	$9,000^{a}$	$1,000^{d}$	$48,000^{a}$	$111,000^{b}$	
	$9,000^{b}$		$48,000^{b}$		$111,000^{b}$
	$3,600^{d}$	$2,800^{c}$			$50,000^{d}$
134_{Cs}	$5,555^{a}$		$30,000^{a}$		$74,000^{a}$
	$5,555^{b}$		$30,000^{b}$		$74,000^{b}$
	$3,100^{c}$			$500,000^{d}$	$43,000^{d}$
90_{Sr}	333^{a}		$4,900^{a}$		
	333^{b}		$4,900^{b}$		$18,500^{b}$
	$1,200^{d}$				$28,000^{d}$
89_{Sr}	$5,200^{a}$		$111,000^{s}$	$300,000^{a}$	
	$5,200^{b}$		$111,000^{b}$		$300,000^{b}$

Total Intake^{a} (Emergency Protective Action Guides)

131_{I}	3,333
134_{Cs}	148,000
137_{Cs}	260,000
90_{Sr}	7,400
89_{Sr}	95,000

a. Federal Register (1982)
b. FDA (1986
c. Engel (1986)
d. Clark (1986)

most radiation-induced cancers occur in the adult population, since the average latent period for solid tumors is 20 to 30 years. Radiation-induced leukemia seems to have a 2 to 10-year latency. Even though high levels of ionizing radiation can increase the incidence of cancer, radiation is used in many types of cancer therapy, because many cancer cells are more sensitive to radiation than the normal cells.

In the 80,000 survivors of Hiroshima and Nagasaki, the Atomic Bomb Casualty Commission (ABCC) reports an increase of about 5% in cancer rate compared with the 28,000 controls. Of the 23,499 deaths from all causes, 4,575 were from cancer at the time of the 1984 report and only 251 were probably from radiation (Mettler Ref p 35). In the 46,000 military personnel who were involved in the atomic bomb tests in the Pacific and at Nevada Test Site (NTS), no evidence was found for an increase in cancer deaths. The lower incidences of cancer deaths than expected among these service personnel may be due to the good physical condition of the individuals involved (Marwich 1985). Much speculation has been made on the thousands of cancer deaths to be expected from the Chernobyl accident. However, the estimates from Vienna are that in Western USSR over the next 70 years, there will be only a 0.05% increase in cancer deaths due to the exposure to short-lived fission products (mostly iodine) and an 0.4% increase due to the long-lived fission products (mostly cesium-137) (Norman 1986).

Cancer increases can be effectively measured if exposures are above 100 R, but extrapolation to effects from low levels of exposure may provide erroneous data. There is little human data on low level effects, and most animal data indicate that radiation cancer effects will be overestimated if the data are extrapolated in very low doses. There are some indications that very low level exposures increase the chance of tissue repair and recovery so low level effects may never be measurable.

Cancer developed on the backs of three Hereford cows 15 years after an estimated dose of 57,000 rad to the surface of the skin. This fallout dose came from downwind of the first atomic bomb test near Alamogordo, New Mexico, in July of 1945. Small areas of squameous cell carcinomas developed after the average productive life expected for Hereford cows; these cows were estimated to be at least 3 years of age at time of exposure. No increase was observed in the incidence of ''cancer eye'' in these cows compared with the control group (Brown et al. 1966). Another example of cancer from beta exposure was observed in a wether which developed severe diarrhea after being fed 20 mCi cerium-144 daily for 14 days. After 22 months, this animal developed carcinoma near the dock where radioactivity accumulated in the wool (West and Bell 1974). Most farm animals are not kept for longevity, so the chance of observing cancer from whole body gamma exposures are very small.

Risks From Exposure To Ionizing Radiation

Evidence suggests that ionizing radiation has always been one of the constituents of the universe. Geological time has been mapped using the concentration of several radioisotopes and their decay products. Background radiation varies on earth and the altitude above the earth. No significant effects on the Chinese have been found from over 70,000 people living in an area with background radiation 3 times the level of a similar group of controls (Bell 1985).

Lethal and near lethal levels of ionizing radiation effects on humans and on agriculture are well documented. However, data on effects of small increases in background radiation are elusive and somewhat contradictory. Data available on nonmammals show more improvement on reproduction and productivity than detrimental effects (Luckey 1982). Stimuli have often been shown to cause positive responses unless the organisms are overwhelmed by the stimuli.

No recorded deaths in the United States can be traced to commercial nuclear power reactor accidents; however, accidental exposures in human medicine and improperly used medical radiation devices have resulted in lethal human exposures. No measurable effects on agricultural plants and animals have been recorded from accidental exposure to radiation from nuclear power or other peaceful uses of ionizing radiation. No deaths from transportation of radioactive materials have occurred in the U.S., even though public surveys list this as a major concern (Abelson 1986). Radioactive fallout from atomic bomb tests has shown measurable effects on livestock.

If the nuclear power plant system in this country were greatly expanded, the additional average dose above background and all other sources would only be about one millirem per person per year (Bodansky 1980). Natural background radiation averages about 100 times this level. At present, the amount of radiation received from nuclear power plants under normal conditions is less than the amount of radionuclides emitted from coal-fired power plants, as mentioned under possible sources of radioactive contamination. In fact, a preliminary study by the Environmental Protection Agency that rated coal up to 80 times riskier than nuclear power reactors in terms of the radionuclides given off during normal operation suggested that coal-fired power plants present greater risks to the public of developing cancer from radionuclides than a normally operating nuclear plant. (Agres 1980).

In view of these facts, the role of nuclear power must be looked at in relation to other risks incurred in everyday life. Nuclear power itself has not only been shown to be useful, but it can also be harmful. The question of radiation is not just one dealing with nuclear power plants; it deals also with background, coal fired power plants, medical X-rays, radiation treatments, jet flights, cardiac pacemakers, watches, smoke detectors, artificial teeth, and nuclear explosions (Haaland 1979).

If nuclear power production throughout the world ceased, we would experience about a 50% increase in the cost of electricity and an energy shortage using the present technology available. Nuclear power plants in the United States are extremely safe—safer and cleaner than other forms of energy production. Many of the so called "unacceptable risks" of nuclear power are based on unfounded hysteria and are not based on factual information. In the United States, 16% of electricity is produced from nuclear power compared with 19% in Great Britian, 31% in West Germany and 65% in France (Dickson 1986). In France, electricity from nuclear power costs 2/3 as much as that produced from coal. Construction costs of nuclear power plants in France are 35 to 60% lower than in the United States. They have a streamlined licensing system compared with that of the United States. According to a U.S. Nuclear Regulatory Commission report no major differences exist in safety of U.S. and French nuclear power plants.

Okrent (1987) reviewed the U.S. Nuclear Regulatory Commission Policy Statement goals which state that (1) "individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that they bear no significant additional risk to life and health" and (2) "societal risks to life and health from nuclear power should be comparable or less than the risks of generating electricity by viable competing technologies." The first goal appears to be unrealistic and incompatible with the second goal.

Most members of the public make rational risk decisions. Whatever we do involves some risk, so we should continue to reduce risks or at least reduce them to levels comparable to other risks. We should not single out any one industry and decide that any risk at all in that industry is intolerable. Results of zero risk levels for radiation exposures, nuclear reactors, or the environment can only mean stagnation of a production industry, increase in the pollution monitoring industry, and an increase in costs with the eventual decrease in the quality of life.

Summary

Nuclear radiation, radioisotopes, and nuclear power are widely used throughout the world for the benefit of humankind.

Nuclear power reactors are producing electricity in the United States and throughout the world. From the data available, the nuclear power reactor industry appears to be as safe, if not safer, than most other industries for the production of electricity. Nuclear power reactors cannot explode like an atomic bomb. Danger to humans from the TMI and Chernobyl accidents appears to have been much less than anticipated.

Protective Action Guides to protect people and the food supply have been established for action in the event of major nuclear accidents. The possibility of major contamination of the agricultural community downwind from a nuclear power accident appears to be unlikely. If some release occurred, radioactive isotopes of iodine in the food chain to humans would be the primary concern. These could enter by way of milk from grazing cows and from fresh leafy vegetables produced downwind from the accident. Radioactive cesium could also be volatilized, but not to the extent of iodine. Radioactive strontium is less apt to be released. The noble gases krypton and xenon and the heavy metals such as uranium and plutonium are not absorbed and retained by humans and animals, so, if released, they are of no real threat to agricultural food chains to humans.

Countermeasures for the agricultural community would consist of removing all milk-producing animals from pasture and giving stored feed where required by the Protective Action Guide. Milk above safe levels would be stored until safe, diverted to other uses, or simply dispersed with waste water. Fresh leafy vegetables could be washed and outer leaves removed, or the vegetables could be destroyed if levels were unsafe. Appropriate guidelines based on accurate information would be helpful in the aftermath of any large radiation accident.

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Glossary of Terms

Background-the radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements.

Becquerel (Bq)-the amount of radioactivity equal to 27 pCi. Becquerels are usually quoted per unit volume in liters (1) or weight in grams (g) or kilograms (kg).

Core-The active portion of a nuclear reactor, containing the fissionable material.

Critical-capable of sustaining a chain reaction at a constant level.

Critical reactor-a nuclear reactor in which the ratio of moderator to fuel is either subcritical or just critical.

Curie (Ci)-the unit used in measuring radioactivity, equal to the quantity of any radioactive material in which the number of disintegrations per second is 3.7×10^{10}. One Ci equals 37,000,000,000 Bq.

Dosimeter-an instrument that measures the total dose of nuclear radiation received in a given period.

Fission-the splitting of an atomic nucleus into two parts of approximately equal size, accompanied by the conversion of part of the mass into energy.

Fission product-any radioactive or stable nuclide resulting from fission, including both primary fission fragments and their radioactive decay products.

Half-life-the time it takes for disintegration (decay) of half the atoms in a given amount of radioactive material.

Lethal dose 50 (LD-50)-the dose of a substance that is fatal to 50% of a specific group.

Metric abbreviations:

1,000 picocuries (pCi) = 1 nCi - 10^{-9}
1,000 nanocuries (nCi) = 1 uCi - 10^{-6}
1,000 microcuries (uCi) = 1 mCi - 10^{-3}
1,000 millicuries (mCi) = 1 Ci
1,000 curies (Ci) = 1 kCi - 10^{3}
1,000 kilocuries (kCi) = 1 MCi - 10^{6}
1,000 megacuries (MCi) = 1 GCi - 10^{9}

Nuclear reactor-a device containing fissionable material in sufficient quantity and so arranged as to be capable of maintaining a controlled, self-sustaining nuclear fission chain reaction.

Rad-a unit of absorbed dose, equal to energy absorption of 100 ergs per gram (0.01 joule per kilogram). One rad equals slightly more than one roentgen.

Radioactive-giving off, or capable of giving off, radiant energy in the form of particles or rays, as alpha, beta and gamma rays, by the spontaneous disintegration of atomic nuclei.

Radioactive decay-the spontaneous transformation of a nuclide into one or more different nuclides, accompanied by either the emission of particles from the nucleus, nuclear capture or ejection of orbital electrons, of fission.

Radioisotope-a naturally occurring or artificially created radioactive isotope of a chemical element.

Rem-a unit of ionizing radiation, equal to the amount that produces the same damage to humans as one roentgen of high-voltage X-rays; derived from roentgen equivalent man (rem).

Roentgen-a quantity used in measuring ionizing radiation, from X-rays or gamma rays, equal to the quantity of radiation that will produce, in 0.001293 grams (1 cc) of dry air at 0° and 760 mm mercury pressure, ions carrying one electrostatic unit of electricity of either sign; abbreviated as R. One R equals about 0.87 rads in air or 0.96 rads exposure in tissue.

Supercritical reactor-a nuclear reactor in which the effective multiplication constant is greater than one and consequently a reactor that is increasing its power level; if uncontrolled, a supercritical reactor will undergo a sudden and dangerous rise in power level.

Zero-power reactor-an experimental nuclear reactor operated at low neutron flux and at a power level so low that no forced cooling is required; fission product activity in the fuel is then sufficiently low to permit handling of the fuel after use.

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