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Possible Effects of Nuclear Power Reactor Accidents On Agriculture

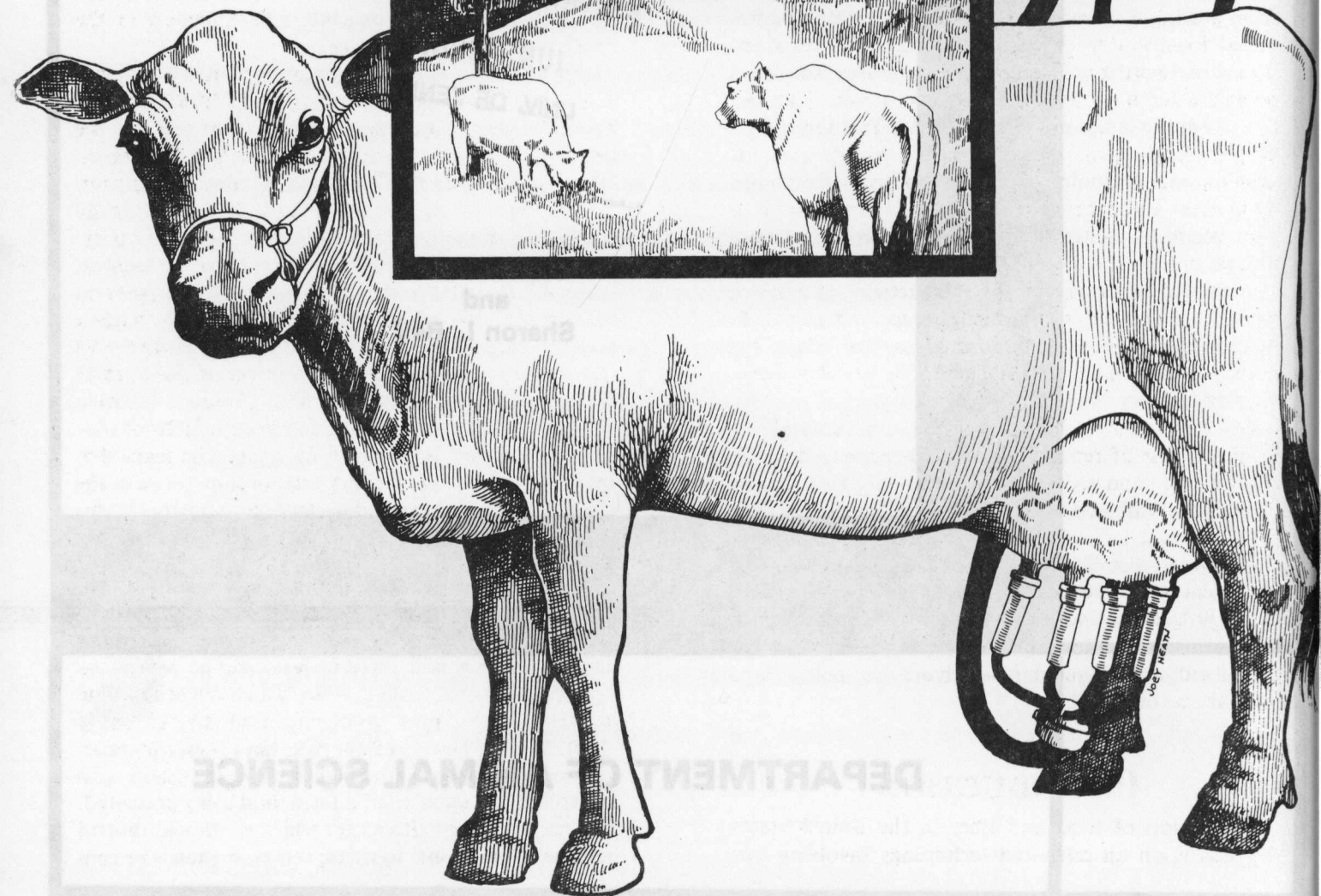
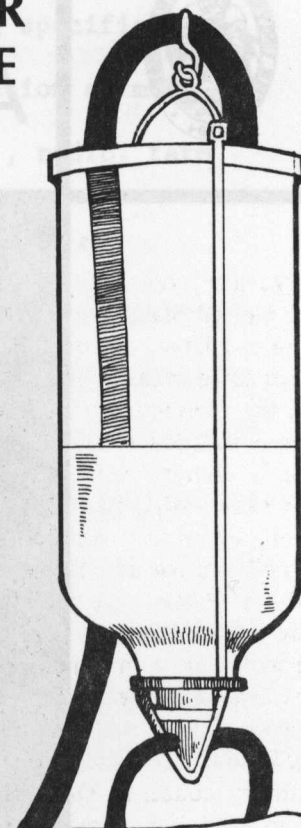
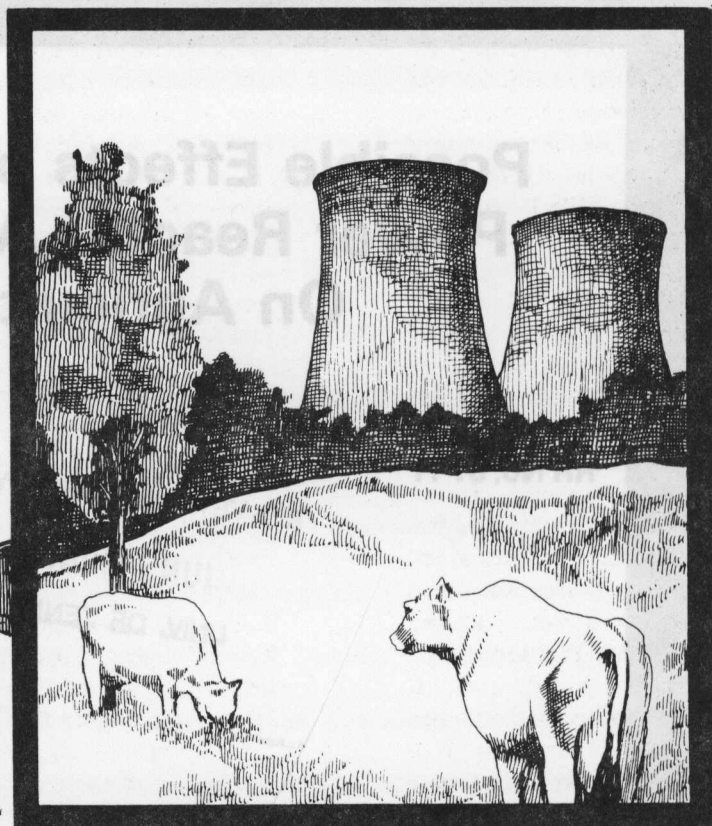
RR No. 81-11

June, 1981

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DEPARTMENT OF ANIMAL SCIENCE

POSSIBLE EFFECTS OF NUCLEAR POWER REACTOR ACCIDENTS ON AGRICULTURE



Possible Effects of Nuclear Power Reactor Accidents on Agriculture

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ABSTRACT

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. A popular misconception is that nuclear reactors will explode like an atomic bomb. Danger to humans appears to have been much less than anticipated from the Three Mile Island accident. Protective Action Guides (PAG's) have been established for action in the event of major nuclear accidents. PAGs were not exceeded at Three Mile Island. The possibility of major contamination of the agricultural community downwind from a nuclear power plant appears to be unlikely. In the event of action on PAGs, radioactive isotopes of iodine through the food chain to humans are the radioactive isotopes of primary concern. These could enter by way of milk from grazing cows and from fresh leafy vegetables produced downwind from the accident. Other routes of entry are not worth considering. Radioactive cesium could 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 they are of no real threat to agricultural food chains to humans. In comparison with natural background radiation, medical uses of radiation sources and other sources of radioactivity, the added amount of radiation from nuclear reactor power production is very small, amounting to less than 1% of the natural background, even at Three Mile Island accident vicinity.

Countermeasures for the agricultural community would consist of removing all milk-producing animals from pasture and giving stored feed where PAG action is required. 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, outer leaves removed or destroyed if levels are unsafe. Good judgement and a cool head would be helpful in times when a few doomsday prophets are flooding the media with rumors and data which are not applicable to nuclear reactor accidents.

INTRODUCTION

Production of food and fiber in the United States depends upon an advanced technology involving less

than five percent of the population. 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 we export our surplus of over half of our food grains in order to pay for some of our expensive imports such as oil. Also, some of our food exports are gifts to feed starving people throughout the world. To continue a viable agriculture we need a continuous supply of energy from whatever sources are available. We need to continue to produce food which is relatively safe from risk to humans. This safety should be considered in relation to the other risks in life. People, dairy farms and power plants go hand-in-hand in this country because where the people are, there is a need for food and a need for energy. In fact, over 75 percent of the United States' total milk cows are located in states with one or more operating nuclear power reactors (Halsey 1980c). The stress on milk in this report is because milk is the primary route of radionuclide contamination in the food chain to humans.

Dairy product consumption in the United States was 329 pounds per capita last year (Anon. 1979), which is about 27 percent of the total volume of diet for the general population (Shleien *et al.* 1977). The dairy farms which supply this need are located near the greatest population centers. The Northeast with its heavily populated areas counts two of the top ten dairy-producing states in its ranks; the Midwest has eight of these. Along with the high dairy production, these areas account for over 63 percent of the total U.S. nuclear power plants in operation. In the Midwest there are 22 nuclear power plants and in the Northeast there are 23 nuclear power plants (Anon. 1980). These are followed by the South with 20 plants, the West and Northwest with six and the Southwest with none. The maps that follow illustrate the definite relationship between the location of dairy cows and nuclear power reactors in this country (figures 1 and 2).

Nuclear power reactors are already a reality in providing part of our electrical energy demands. It is one of the many workable energy sources which we have continued to explore and develop. A nuclear power reactor simply heats water, making steam which drives a turbine of a generator, thus producing electricity (Kemeny 1979). Nuclear power reactor risks have been continually brought to our attention with inconsistent and sometimes sensationalized information being presented. It is not an energy alternative which we should discard because of emotional hysteria; rather, it should be con-

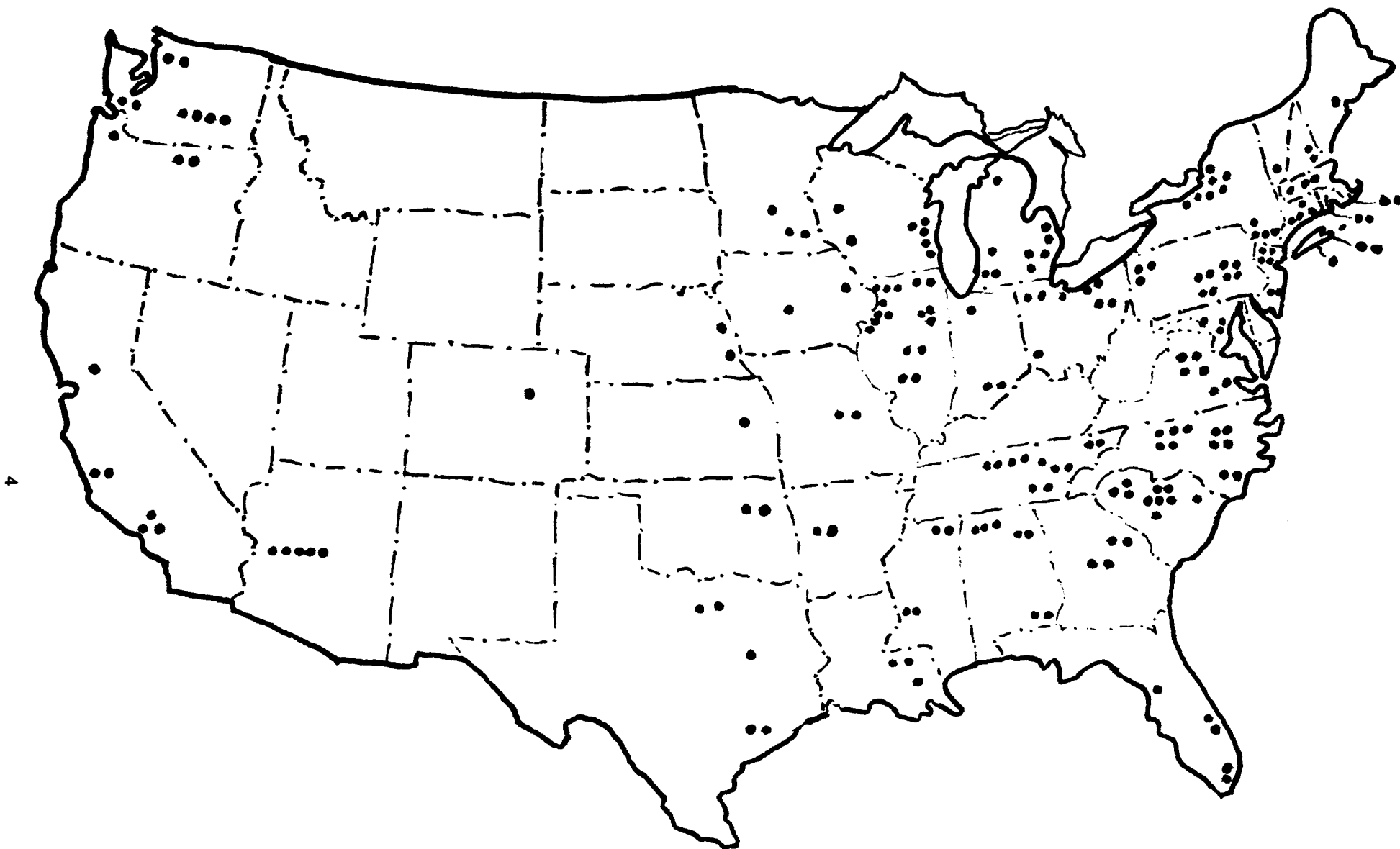


Figure 1. Nuclear power reactors in the United States, including reactors licensed to operate, being built and planned. (Halsey 1980c)

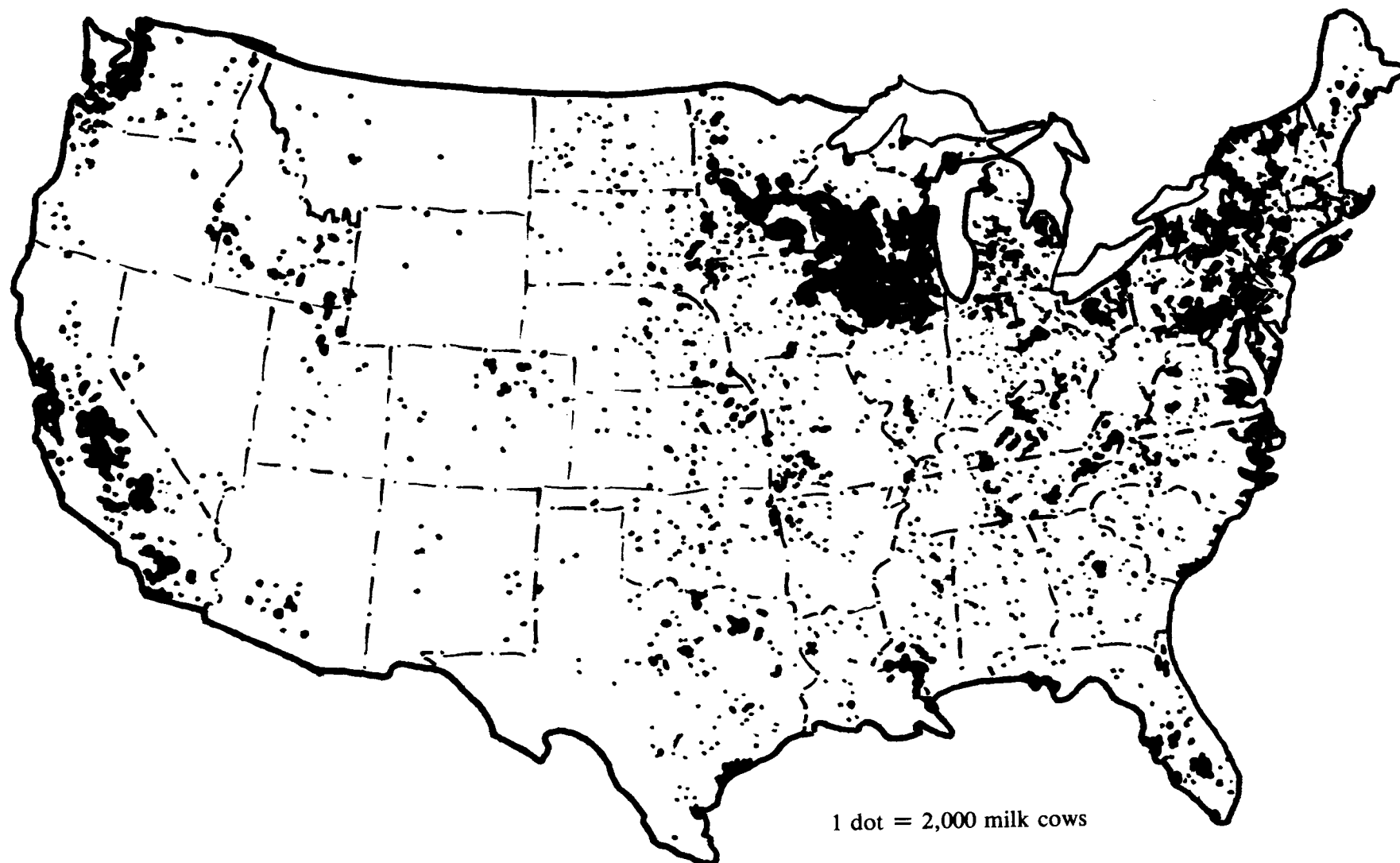


Figure 2. Density of United States milk cow population (1974). (Halsey 1980c)

sidered along with other options based on risks and costs. Perhaps the consequences of not having nuclear power reactors should also be very carefully considered and weighed. Resistance to technological advances is not new. Simon (1980) suggests that phony bad news and false statements may be made for a number of reasons. These include selling of books, newspapers, magazines, obtaining of funds for research efforts, and to strive for an unrealistic idealistic utopian state of affairs.

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

HISTORY OF NUCLEAR POWER REACTOR ACCIDENTS

Windscale Atomic Pile No. 1 — October 10, 1957. Inadequate instrumentation for maintenance operations and poor judgement on the part of the operating staff combined to cause an overheating accident at the No. 1 atomic pile of the plutonium-producing facility at Windscale, England (Bishop 1959; Anon. 1957).

Workers who were in the immediate facility were tested and observed after the accident. For the 13 week reading on dosimeter badges, which included the time of the accident, only 14 workers directly associated with the accident exceeded the maximum permissible level of irradiation. The International Commission on Radiation Protection (ICRP) tolerance level for 13 weeks was then 3.0 r. The highest figure measured from the badges was 4.66 r (Anon. 1957). Per thyroid the highest level was only 0.5 uCi. A report to the British Parliament shortly after the accident said: "Since iodine has a short life some increase over the ICRP level can properly be made if the dose occurs on a single occasion" (Anon. 1957).

Public concern mounted and precautions were taken to ensure uncontaminated food supplies. In order to protect children from possible contamination with fission products released from the accident, milk supplies in the area were condemned for human consumption if samples showed 0.1 uCi/liter of radioiodine (Chamberlain and Dunster 1958; Anon. 1957). Milk distribution was under restriction for two to five weeks in a coastal area near the accident about 30 miles long, 10 miles wide at one end and six miles at the other end (Anon. 1957; Ward 1961). Other sources of possible contamination were checked in the area and found not to be harmful, and thus no restrictions were placed on any of these (Anon. 1957; Chamberlain and Dunster 1958).

The report to the British Parliament said, "We feel that 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 incident" (Anon. 1957).

Vinca, Yugoslavia — October 15, 1958. An accident at Vinca, a suburb of Belgrade, occurred at a zero-power reactor built for experimental purposes (Savic 1959). The accident involved a brief uncontrolled run at the assembly, allowed to go undetected because of the lack of an interlock system and the fact that the safety circuits and monitors were turned off at the time.

At the time of supercriticality, eight persons were in the immediate area around the tank and were exposed to very large doses of neutrons and ionizing radiation (Anon. 1960b). Total body radiation absorbed internally was between 300 and 1500 roentgens (Anon. 1959). With a dose of 400 to 500 roentgens considered lethal in 50 percent of cases exposed (Anon. 1960b), the amount received by the Yugoslavian workers was well above normal at an average of 683 rems. One person died, and the seven others were treated and apparently suffered no complications. No material escaped the facility.

Three Mile Island, Goldsboro, PA — March 28, 1979. The accident at Three Mile Island (TMI) number two reactor resulted from a series of equipment malfunctions complicated by human misjudgement. The story of TMI has been told and retold but the actual series of events that culminated in the worst nuclear accident that this country has seen may never be fully understood.

Three Mile Island reactor, completed in December 1978, is a pressurized water reactor that can produce 880 megawatts of power.

The accident apparently started when a turbine trip let off nonradioactive steam into the outside atmosphere at 100 psi on the morning of March 28. Events followed that led to what was termed a general emergency at the plant. What followed was a general state of confusion as well. Part of the confusion resulted from the lack of direct authority for just such an emergency. On the scene were representatives of various government agencies, state regulators and assorted media personnel. Reports were handed down from the 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 left the people in the surrounding areas with virtually no real center of authority to turn to for recommendations during the crisis time. A warning from 1961 rang true: "An accident of the type at Windscale, followed by indecision and vacillating directives could do irreparable harm to the nuclear energy program in the United States" (Ward 1961).

Equipment failures and operator errors resulted in coolant levels in the pressure vessel falling below the top of the core, resulting in its serious overheating. Claims abounded that the core would melt down, expelling massive amounts of 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 were to happen the fissionable material would be in a less condensed mass so this would reduce the fission rate and in turn reduce the temperature.

As it happened the core was severely damaged but didn't melt down. There were releases of radioactive gases from the TMI facility in the form of xenon-133 and krypton-85, noble gases which are not retained in the human body. About 15 Ci of radioactive iodine was released into the atmosphere. "The health effects of this iodine were insignificant" (Burnett 1980). Sampling at 375 kilometers of the air mass containing gas released from the TMI plant showed that the "whole-body dose to an individual . . . from exposure to gamma rays and X-rays from the passing xenon-133 . . . was 0.004 mrem" which is about 0.004 percent of the amount received from natural sources (Wahlen *et al.* 1980).

The facility is located in the middle of the Susquehanna River just south of the state capital of Harrisburg. In this area there are over 100 dairy farms within 50 miles of the plant. There was a total of 8,490 dairy cattle, 1,880 beef cattle, 475 swine, 100 sheep, 70 horses and 18 goats on 100 farms surveyed by the Pennsylvania Department of Agriculture in May following the accident (Halsey 1980b). There are 630,000 people in a 20-mile radius of the plant.

Because of concern that there might be iodine-131 in the air, testing of milk was started the day of the accident. During the first crucial days following the accident, 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 16 to 41 picocuries per liter (Halsey 1980a). This amount was significantly below the 12,000 picocuries per liter at which milk is considered unsafe to drink and the 400 picocuries per liter in Pennsylvania from 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 from TMI (Krieg 1979)].

In a survey conducted by the editor of Dairy Herd Management magazine of their readers in the seven-county area surrounding TMI, only one percent of the respondents moved their cows to another location during the height of the crisis. Ninety-three percent didn't even consider moving them. Only one percent of the dairymen dumped 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 increased also as consumers received daily doses of new terrors via media broadcasts and publications. Of farmers surveyed in the area, 69 percent said they felt the media overplayed the incident and 68 percent said they thought their milk sales were hurt by TMI plant shutdown (Halsey 1980b).

Bill Fouse, head of 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 TMI plant that actual release of radioactivity will have a negligible effect on individuals. Mental stress was the main effect!

POSSIBLE RADIOACTIVE CONTAMINATION

Sources. It is very important in discussing radiation to remember that radioactivity is not a new creation. It occurs naturally and for over 50 years man has used it for his own purposes. Naturally-occurring radioactivity can be found in the earth's crust, building materials, drinking water, space, people and animals (Lenihan 1959). All species have evolved with radiation from cosmic rays and radioactive minerals. Man, too, has developed with different levels of natural radiation found throughout the world.

In southwest France, natural radioactivity exposure from two natural uranium isotopes exceeds 100 rads a year (Leonard *et al.* 1979). This area in southern France and in northern Italy is known for its health spas that advertise curative powers from mud and waters that are high in alpha rays. These centers command high prices and send out many pleased customers who claim benefits from the naturally-occurring radiation (Hollander 1980).

Areas of the United States also are naturally high in radiation. In Denver, for example, estimates are from 130 to 230 millirem per person per year; for the whole country, 80 to 105 millirem. In addition to this background radiation, other sources contribute to total yearly dosage. Medical treatments add an average of another 70 millirems to the total per person per year (EPA 1977; Bodansky 1980).

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. 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 do manage to 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 and the adverse health effects are also expected to decrease. However, the present figures for fatalities from coal are higher than those for nuclear power (Bodansky 1980) (table 1). This comparison is not intended to incriminate coal for its very small amount of radioactivity but merely to demonstrate that there are sources of radioactivity in addition to that contributed by nuclear power plants.

Coal from different parts of the country contains various levels of radionuclides. Coal types from all parts of the United States averaged one part per million for uranium and two ppm for thorium (McBride *et al.* 1978). Some coals were 10 to 40 times higher in concen-

tration than the averages; anthracite from Pennsylvania was the highest in thorium, and lignite from the Gulf States — Alabama, Arkansas and Mississippi — was highest in uranium (McBride *et al.* 1978). All uranium and thorium regardless of source is radioactive. Both of these elements occur in several isotopic forms and their radiation emissions vary in intensity, form and energy.

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).

Other than medical uses of ionizing radiation, most of the experience with high levels of radiation has been with radioactive fallout resulting from nuclear weapons tests during the 1950s and 1960s — the Cold War period. The United States did much of its testing at Nevada Test Site and on small, uninhabited islands in the Pacific Ocean, and some accidental exposure occurred. There were accidental exposures to residents on the Marshall Islands on March 1, 1954 when wind directions shifted unexpectedly and carried "significant amounts of fallout" to the islands of Rongelap, Ailingnae and Utirik. The amounts of whole body gamma radiation ranged from 175 r on Rongelap, 69 r on Ailingnae to 14 r on Utirik (Sutow *et al.* 1965).

None of the residents or Utirik developed radiation symptoms, but the residents of the other two islands showed signs and later showed some latent effects of their exposure.

Experimental procedures have shown varying effects of radiation on animals. It is noteworthy that 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 gamma rays per year to rabbits caused small increases in chromosome aberrations in the blood lymphocytes; while there was "no effect on the spermatozoa of male mice similarly exposed, nor of their offspring" (Leonard *et al.* 1979). From these and similar studies, it appears that chromosome aberrations 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" (Anon. 1966). 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

Table 1. Estimated annual fatalities resulting routinely from the generation of one GW-year of electricity, in coal-fired and nuclear plants. The estimates include the complete fuel cycle excluding reactor accidents.
Bodansky, 1980)

Cause	Fatalities per GW-year
Coal	
Accidents, mining	0.8
Accidents, transportation	1 to 2
Total	2 to 3
Pollution, new plants with lime scrubbers	0.007 to 17
Pollution, old plants, 3 percent sulfur coal	3 to 170
Total Coal:	2 to 170
Nuclear Power	
Nonradiation accidents (mining)	0.4
Radiation, occupational	0.3
Radiation, public	0.2
Total radiation	0.5
Total Nuclear:	0.9

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 in fact be induced, but the deviations were probably fatal to the fertilized eggs (Anon. 1966).

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 operating a nuclear reactor power plant must be considered in relation to other risks encountered in everyday life.

Nuclear Reactor Accidents. There are four general classifications of nuclear power reactor accidents as defined by the Nuclear Regulatory Commission: notification of unusual event, alert, site emergency, and general emergency (table 2).

Thus, in terms of specific accidents, there are some types that can occur. The two types of concern from the public standpoint are loss of coolant accidents (LOCA) and fuel meltdowns.

"It now seems probable that the worst possible accident from the point of view of the exposure to the public to ionizing radiation is not a runaway nuclear reaction, but a loss of coolant accident," said Professor Richard Wilson in 1973. He explained that the accident could happen if the cooling system in the reactor vessel or steam piping failed. 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).

A meltdown could occur "if no steps were taken to re-establish core cooling" (Wilson 1973). In both the Kemeny Commission Report (the President's special committee charged with investigating the Three Mile Island incident) and the Rogovin Report (the NRC's inquiry of TMI) conclusions were drawn that a core meltdown would probably not have gone through the containment building and even if it did, either the bedrock or the soil below the facility would not have allowed the melted core to go anywhere (Burnett 1980).

The question of explosions in nuclear power reactors is one of little concern. In 1969, Dr. Karl Z. Morgan, then director of Health Physics Division of Oak Ridge National Laboratory, 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). Earlier, in 1965, Dr. A. B. Park of Agricultural Research with USDA told a veterinary medical convention that if an explosion did occur, it would "be about the same explosive hazard as a boiler blowing up" (Park and Todd 1965).

A Kemeny conclusion was that at TMI the hydrogen bubble inside the pressure vessel could not have exploded

Table 2. 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 unit.
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 off-site (within 10 miles) once in about 100,000 years per unit.

ed or ruptured the pressure vessel (Burnett 1980). Nuclear reactors are designed so that it is impossible for them to explode like an atomic bomb (Kemeny 1979).

The following table (table 3) includes estimates for airborne activity that could be available for release from containment in the event of some types of accident sequences.

POSSIBLE FOOD CHAIN CONTAMINATION

Dairy cows play an important link in the human food chain by supplying nutrients, using sources of nutrients that humans can't directly use and filtering out

undesirables from the diet.

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, increased iodine excretion with some increase in thyroid iodine. Iodine losses from normal intake include 30 percent of the intake lost in feces, 40 percent in urine and eight percent in milk. (Dairy cows secrete less iodine in milk than most other species.) Cows have different levels of iodine in their milk at different stages of lactation with a higher percent dose per liter occurring in the later stages. However, a mixed herd of cows will be at different stages and this will not play an important part in the level of radioiodine in the

The peak concentration of ^{131}I 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 eight percent of the daily intake of ^{131}I is secreted into each day's milk" (Comar 1965).

The physical half-life of ^{131}I is eight days, but experimental work has shown that on undisturbed pasture it may vary from three to six days — usually occurring at five days — for the biological half-life (Sasser and Hawley 1966). Dilution of the ^{131}I could be from rain-

Table 3. Comparison of Kemeny Commission estimate for postulated meltdown with "design basis" LOCA and with Rasmussen (Burnett 1980)

Time (1)		Percent of core fission product inventory that is airborne							
		Xe-Kr	Org. I	I	Cs-Rb	Te-Sb	Sr-Ba	Ru ⁽²⁾	La ⁽³⁾
"Design Basis" LOCA									
No meltdown, TID releases	0	100%		25%	---	---	---	---	---
	1 hr	100%		0.25%	---	---	---	---	---
Rasmussen Release to Atmosphere									
Worst containment failure (PWR-1/2)	---	90%	0.7%	70%	50%	40%	6%	40%	0.4%
Containment leak, no spray (PWR-4)	---	60	0.2	9.	4.	3.	0.5	.3	0.04
Containment leak, spray (PWR-5)	---	30	0.2	3.	0.9	0.5	0.1	0.06	0.007
Kemeny Estimates for TMI									
Postulated Meltdown	Max.	100%	0.001-0.2	3.	1.	5.	0.06	0.3	6x10 ⁻⁵
(4) (Airborne activity in containment building)	1 hr	100%	0.001-0.2	0.4	1.	5.	0.06	0.3	6x10 ⁻⁵
	6 hr	100%	0.001-0.2	0.09	0.1	0.6	0.008	0.04	7x10 ⁻⁶
	24 hr	100%	0.0006-0.1	0.03	10 ⁻⁴	5x10 ⁻⁴	6x10 ⁻⁶	3x10 ⁻⁵	6x10 ⁻⁹
	240 hr	100%	10 ⁻⁸ -10 ⁻⁶	0.0002	10 ⁻⁴	5x10 ⁻⁴	6x10 ⁻⁶	3x10 ⁻⁵	6x10 ⁻⁹

⁽¹⁾Time after release into the containment. For Kemeny work, release into containment was taken at the time the core melted through the reactor vessel (7 hours after the beginning of the accident, and 4 hours after the start of fuel melting).

⁽²⁾Includes Mo, Rh, Tc, Co

⁽³⁾Includes Nd, Y, Ce, Pr, Nb, Am, Cm, Pu, Np, Zr

⁽⁴⁾Compiled from Kemeny "Technical Staff Analysis Report on Alternate Event Sequences," Appendix E "Fission Products Inventory Within the Containment," and Appendix G "Analysis of Fission Product Release to the Containment Atmosphere."

milk (Tamplin 1965). Even after secretion into the mammary gland much of the iodine is available for resorption (Miller *et al.* 1975).

Radioisotopes of iodine would be the main concern from a nuclear reactor with ^{131}I as the predominant one. Contaminated fresh milk is the main contributor of ^{131}I to the human diet. Inhalation of ^{131}I 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 to remove large amounts of the isotope. Milk, on the other hand, is of major concern because of its short market time.

fall, wind, mechanical disturbance or new growth.

Swedish researchers found that of the iodine-131 deposited on pasture area considerable volatilization occurred before the cows were even put on the pasture. Between the time the pasture was sprayed and the time cows were placed on it to graze (18 hours) about 60 percent of the iodine-131 deposited had disappeared. While the cows were grazing over the next three days an additional six percent disappeared: thus, about two percent was eaten by the cows (Auraldsson *et al.* 1971).

Since many dairy cattle are only on pasture during their dry period, the possibility of contamination is greatly reduced. However, it must be considered that

some cows could receive contaminating doses of radioiodine and pass it on in milk.

Radioiodine may get into the cow diet via ingestion of contaminated 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 some iodine but less than pastures.

Exposed cattle may be fed massive doses of stable iodine to reduce the ^{131}I content in milk. Feeding 1.3 g reduced the level in milk by one-third and 2.0 g reduced it one-half when fed daily on experiment (Miller *et al.* 1975). Cattle other than lactating cows are of no real concern to the food chain with respect to iodine-131 due to the decay of radioactive iodine and to the delay time from grazing cattle to meat consumption.

Radioiodine contamination of fresh vegetables and fruits is not a problem with commercially-produced foods because of the transit time from harvest to market. However, home gardens could supply contaminated foodstuffs from radioactivity deposited on the surface of leafy vegetables. These vegetables, because of their proximity to the consumers, may undergo only a 24-hour holding period (or less) before they are used (Thompson 1967). This time period does not allow for sufficient radioactive decay of ^{131}I . Direct consumption of ^{131}I in water might be a problem in cisterns but not for wells and treated municipal water supplies.

Strontium. 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 Ca and ^{90}Sr 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 in soils that have a low level of calcium (Lenihan 1959).

The amount of contamination that a cow passes along in her milk will be much less than the amount ingested, for she "always puts into milk less of the strontium than the calcium that is in the ration" (Comar 1965).

Strontium-89, with a much shortened half-life of 50 days, moves through the food chain like strontium-90, but in an abbreviated version.

Cesium. Cesium-137 enters plants by direct contamination and can, therefore, be easily removed from plants by rainfall. Almost none of the cesium is taken up from the soil, probably because of the "fixation in the lattice structure of clay minerals."

Once in an animal's body, cesium-137 is metabolized like potassium and moves through the gastrointestinal tract and on to the muscle tissues (Anon. 1960a). In lactating animals, the cesium passes on 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 is absorbed and 99.99% is excreted in the feces.

Krypton and xenon are inert gases which are poorly soluble in water and tissues (Sagan 1974). From table 4 it is evident that the 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

Table 4. Estimated annual doses to the U.S. population from worldwide distribution of krypton-85 (Eichholz 1976)

Year	Dose			
	Whole-body		Skin	Lung
	(mrem/ person)	(mrem)	(mrem/ person)	(mrem/ person)
1960	0.0001	20	0.005	0.0002
1970	0.0004	80	0.02	0.006
1980	0.003	700	0.1	0.005
1990	0.01	4,000	0.6	0.02
2000	0.04	12,000	1.6	0.06

released into the atmosphere, they 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 and 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 seven hours (Sagan 1974).

RECOMMENDATIONS

In the event of a nuclear power reactor accident that releases fission products into the atmosphere, precautions should be known and action taken at the appropriate time. Emotionalism has no place in the rational control of contamination of our foods. Some recommendations may not apply to everyone as geographic differences and climatic limitations often dictate actions more than do desires. Measures to deal with a possible contamination are given, including the Protective Action Guides (PAGs) set up by the federal government.

Soil. Soil would not be of immediate concern but proper management procedures could do a great deal to reduce a problem should it occur. The addition of lime to calcium-poor soils can reduce the uptake into plants of such radionuclides as strontium-90 and strontium-89.

Vegetables. The greatest amount of contamination reaches vegetables by direct contamination. Rainfall carries radionuclides into cavities of the fresh leafy

vegetables and collects there. For commercially produced vegetables that have a waiting period between harvest and market, this would not be a problem as far as some contaminants are concerned. With vegetables grown at home, skins or outer leaves should be removed and the remainder washed thoroughly. Canning, freezing, or other storage of vegetables would allow decay of short-lived radionuclides.

Grain. For grains, PAG action would probably never be needed, but if so it should include milling and polishing. Time from harvest to consumer would be an important factor here for this, in many cases, may be several months.

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. This would likely 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 other methods used to allow this to occur. Methods exist to remove radionuclides from milk via ion-exchange resin columns; however, to date this process has not been commercially exploited on a large scale and is available in only a few areas. The same principles would be involved as discussed by Bell and Blake (1976) for protection from fallout from nuclear weapons except weapons fallout would be much higher concentration of radioactivity covering much greater areas.

Meat. Meat and meat products would be considered by a case-by-case evaluation according to the PAGs.

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

General. If ^{131}I is the only radionuclide which exceeds PAGs, then storage until safe would be a solution to this problem. Also, contaminated food products could be diverted and fed to livestock other than cows producing milk.

Don't panic. Emotional outbursts by pseudoexperts and unconfirmed rumors should be ignored. Good judgement should be used and local agricultural leaders are easily in contact with radionuclide experts. Food

producers are constantly challenged by emergency situations in their day-to-day operations and the response of the agricultural community around TMI was very admirable.

SUMMARY

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. A popular misconception is that nuclear reactors will explode like an atomic bomb. Danger to humans appears to have been much less than anticipated from the TMI accident. Protective Action Guides (PAGs) have been established for action in the event of major nuclear accidents. PAGs were not exceeded at TMI. The possibility of major contamination of the agricultural community downwind from a nuclear power plant appears to be unlikely. In the event of action on PAGs, radioactive isotopes of iodine through the food chain to humans are the radioactive isotopes of primary concern. These could enter by way of milk from grazing cows and from fresh leafy vegetables produced downwind from the accident. Other routes of entry are not worth considering. Radioactive cesium could 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 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 PAG action is required. 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, outer leaves removed or destroyed if levels are unsafe. Good judgement and a cool head would be helpful in times when a few doomsday prophets are flooding the media with rumors and data which are not applicable to nuclear reactor accidents.

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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

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}

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

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

Metric abbreviations

1,000 millicuries (mCi) = 1 Ci (Curie)

1,000 microcuries (uCi) = 1 mCi

1,000 nanocuries (nCi) = 1 uCi

1,000 picocuries (pCi) = 1 nCi

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 — the standard unit of absorbed dose, equal to energy absorption of 100 ergs per gram (0.01 joule per kilogram); supersedes the roentgen as the unit of dosage

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, or 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 — the international unit of quantity used in measuring ionizing radiation, as 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°C and 760 mm mercury pressure, ions carrying one electrostatic unit of electricity of either sign; abbreviated as R or r

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