
Questioning Food Irradiation

A History of Research Into
the Safety of Irradiated Foods

Public Citizen

Critical Mass Energy and Environment Program

Washington D.C.

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Questioning Food Irradiation

The scientific community is in agreement that food irradiation is among the most thoroughly researched technologies of the 20th century. Where there is no agreement, however, is whether “treating” foods with high doses of ionizing radiation to kill pathogens and extend shelf-life poses health risks to the people who eat these products.

Food irradiation research began in 1921, when a U.S. Department of Agriculture scientist discovered that X-rays killed the *Trichinella spiralis* bacteria commonly found in pork. Two years later, the results of the first animal feeding studies to evaluate the safety and wholesomeness of irradiated foods were published.

In the 80 years since, dozens of foods – bananas, ground pork, onion powder, papayas, beef stew, potatoes, clams, chicken, apricots and many others – have been irradiated and fed to numerous types of animals, mainly rats, mice, dogs, monkeys and hamsters.

At least six experiments involving people – including one involving children – have been conducted.

Virtually every biological assessment of test subjects has been made: animal fetuses have been dissected, biopsies have been taken, DNA and chromosomes have been examined, red and white blood cells have been counted, enzyme levels have been measured, and so on.

Over these eight decades, dozens of studies have drawn into question the safety and whole-

someness of irradiated foods. A wide range of health problems have been observed in animals – and, in a few cases, people – who ate irradiated foods.

Whether the food was “treated” with gamma rays, X-rays or near-speed-of-light electrons, many adverse health effects have been

observed, including but not limited to premature death, mutations and other genetic damage, fetal death and other reproductive problems, residual radioactivity, immune system dysfunction, fatal internal bleeding, a rare form of cancer, organ damage, blood disorders, tumors, nutritional deficiencies and stunted growth.¹

Here are some noteworthy examples:

- A chromosome abnormality called polyploidy – which has been associated with leukemia

and direct exposure to radiation – was detected in children who ate recently irradiated wheat.²

- Polyploidy and a blood disorder were detected in men and women who ate a diet containing a variety of irradiated foods; and elevated red blood cell counts were detected in

Many adverse health effects have been observed in animals fed irradiated foods, including premature death, mutations, fetal death and other reproductive problems, residual radioactivity, immune system dysfunction, fatal internal bleeding, a rare form of cancer, organ damage, blood disorders, tumors, nutritional deficiencies and stunted growth.

Questioning Food Irradiation

men and women who ate irradiated potatoes.³

- The carcinogenesis process was promoted in rats fed a chemical called cyclobutanones, which are formed in certain irradiated foods, and which do not occur naturally in any food.⁴

- “Considerable amounts of radioactivity” were detected in the liver, kidney, stomach, gastrointestinal tract and blood serum of rats fed irradiated sugar.⁵

- Rats fed irradiated beef died from internal bleeding; others fed irradiated beef suffered “general incoordination, spastic hopping gait and sometimes complete loss of movement with dragging hindquarters. Those most severely affected often became completely prostrated a short time before death.”⁶

- In U.S. Army tests, more dogs and rat pups died, and dogs gained less weight than those fed unirradiated foods; and a rare form of cancer developed in rats.⁷

- Rats fed a variety of irradiated foods gave birth to more dead offspring.⁸

- Mice fed recently irradiated food led to embryonic⁹ and fetal deaths,¹⁰ and shorter lifespans.¹¹

- Fruit flies grown in an irradiated medium were born with a variety of mutations.¹²

Additionally, human blood cells exposed to irradiated food components have undergone genetic damage, including “grossly damaged” chromosomes¹³ and “considerable inhibition of mitosis and chromosome fragmentation.”¹⁴

Many researchers who have observed health problems in animals that ate irradiated foods have said that these problems could not be attributed to consuming irradiated foods. Instead, researchers have often made unsubstantiated claims that these health problems were due to dietary factors or experimental anomalies.

In many other cases, researchers who documented health problems in their raw data simply failed to discuss these problems in the summaries and conclusions of their reports. Abnormalities in reproductive performance, blood counts, enzyme levels, organ function, weight gain and other measurements have been recorded, only to be ignored in summaries and conclusions.

This phenomenon led prominent Swedish

radiobiologist and chemist Göran Löfroth – a pioneering DDT researcher – to tell U.S. federal government health officials in 1968: “In my studies of the literature, I have often found a credibility gap between observed parameters and the recurring conclusions that there is no apparent toxic hazard involved in the ingestion of irradiated food.”¹⁵

By downplaying and ignoring raw data suggesting that irradiated foods may not be safe for human consumption, scientists from a wide variety of universities, institutes, organizations and agencies have deprived government officials, the food industry, food scientists and, ultimately, the American people of the complete picture of the potential health problems associated with these products.

By misrepresenting raw data, these scientists have ignored seemingly minor health problems that, in the long term, could result in more serious effects – particularly if multiple problems work in combination, or if problems fester unnoticed for months or years.

This concern was raised in 1968, when then-FDA Associate Commissioner Daniel Banes cautioned members of Congress: “Our knowledge 8 or 10 years ago about the teratogenic [birth defect-causing] effect of drugs – for example, thalidomide and its effects on the embryo – was sketchy. In fact, it was practically nonexistent. The questions we ask now about the effects of drugs on the reproductive process and on metabolic systems and the biochemistry of the body are far more subtle and far more advanced. I submit, sir, that the same situation obtains with respect to irradiated food.”¹⁶

Furthermore, irradiation results in the formation of dozens of chemical compounds, many of which have toxic properties. The scientific record of these chemicals goes back 50 years. During this time, many chemicals known or suspected to cause cancer and birth defects, and chemicals that can damage the central nervous system, have been detected in irradiated foods. Among these are benzene, toluene, methyl ethyl ketone, octane, acetone, ethanol, hexane, heptane and pentane.¹⁷ “Safe” levels for these chemicals in irradiated foods have yet to be determined.

Questioning Food Irradiation

Recently, chemical byproducts formed in irradiated foods called cyclobutanones (or 2-ACBs) were shown to promote the carcinogenesis process in rats, and to cause genetic damage in rats and in human cells. Cyclobutanones have never been found to occur naturally in any food.¹⁸

These findings, coming in four consecutive experiments since 1989, contributed to the European Union's decision in Dec. 2002 against expanding irradiation for several additional types of food, including shrimp, cereal flakes and frog legs. The findings have also delayed a proposal by the Codex Alimentarius Commission - which sets food-safety standard for more than 160 nations - to allow any food to be irradiated at any dose, no matter how high.

In conclusion, the researchers wrote:

[S]ince our results point toward toxic, genotoxic and even tumor promoting activity of certain 2-ACBs, we strongly recommend to carry out further research, including confirmation of our results by other laboratories, to elucidate a possible risk associated with the consumption of irradiated fat-containing foods... Numerous questions still remain to be answered, and much research is left to be done, before a qualified risk assessment can be performed.¹⁹

These findings are particularly disturbing, given that 2-ACBs have been found in numerous foods that contain fat, including beef, chicken, pork, eggs, cheese, fresh- and salt-water fish, salmon, shrimp, mangoes and papayas. The types of fat from which 2-ACBs derive - such as oleic, palmitic and stearic acids - are contained in nearly all foods.

In one study, researchers found 2-ACBs in chicken that was irradiated 13 years earlier.²⁰ 2-ACBs are so easily detected and can be formed at such low radiation doses that they are often used as chemical "markers" to determine whether food has been irradiated. The European Union, for example, has officially adopted this technique to determine whether fat-containing foods have been irradiated.²¹

In addition to concerns related to 2-ACBs, many other warnings have been issued by researchers during the past 50 years.

Among them:

- "An increase in concentration of a mutagen in food by irradiation will increase the incidence of cancer... It will take four to six decades to demonstrate a statistically significant increase in cancer due to mutagens introduced into food by irradiation... When food irradiation is finally prohibited, several decades worth of people with increased cancer incidence will be in the pipeline."²²

- "The thalidomide disaster might have been prevented if an easily performed investigation of possible cytotoxic effects in plant cells had been made. It must be acknowledged that any compound causing [cellular] damage must be considered a potential hazard to any living cell or cell system - including man."²³

- "Irradiating can bring about chemical transformations in food and food components resulting in the formation of potential mutagens... It is now realized, especially since the thalidomide episode, that [older testing] protocols do not detect the more subtle population hazards such as mutagens and teratogens... In view of the serious consequences to the human population which could arise from a high level of induced mutations, it is desirable that protocols for irradiated food should include *in vivo* tests on mammals for possible mutagenicity."²⁴

- "Numerous studies have been carried out to ascertain whether cytotoxic effects occur when unirradiated biological test systems are cultured or fed with irradiated media or food. Adverse physiological (growth retardation and inhibition), cytological (mitotic inhibition and chromosome aberrations) and genetical (forward and reverse mutations) effects have been observed in a wide range of test systems, ranging from bacteriophages to human cells."²⁵

Despite a vast body evidence that irradiated foods may not be safe for human consumption, and despite numerous warnings from researchers, food irradiation has been endorsed by the World Health Organization (WHO), the United Nations' Food and Agriculture Organization (FAO), the International Atomic Energy Agency

Questioning Food Irradiation

(IAEA) and the Codex Alimentarius Commission. And, the process has been legalized in more than 50 countries.

In particular, the WHO has played a role in abandoning the original research agenda it co-drafted in 1961, which urged experiments into whether irradiated foods are toxic or radioactive; whether they could cause cancer, mutations or nutritional deficiencies; and whether the scientific expertise even existed to answer these fundamental questions.

The process by which the U.S. Food and Drug Administration (FDA) has legalized food irradiation has also been flawed. The FDA has legalized irradiation for several major classes of food – including fruit, vegetables, pork, chicken, beef and eggs – despite numerous shortcomings:

- Since 1983, FDA agency officials have knowingly and systematically ignored federal regulations and their own testing protocols that must be followed before irradiated foods can legally be approved for human consumption.
- Since 1986, FDA officials have legalized irradiation for major classes of food while relying on nearly 80 studies that the agency's own expert scientists had dismissed as "deficient." (The FDA legalized the irradiation of eggs in July 2000, for instance, based on three "deficient" studies, one of which was conducted in 1959.)
- None of the seven key studies that FDA officials used to legitimize their first major approval of food irradiation in 1986 met modern standards. (One of them had actually been declared "deficient" by FDA toxicologists; three others had never been translated into English.)
- FDA officials have systematically dismissed evidence suggesting that irradiated food can be toxic and induce genetic damage. Much of this evidence resulted from government-funded research submitted to the FDA and members of Congress as early as 1968.
- FDA, U.S. Army and other federal officials have consistently misled Congress about the potential hazards of food irradiation, and about the reasons that past research initiatives have failed to demonstrate that irradiated food is safe for human consumption.²⁶

Following a rapid expansion of food irradiation in the U.S., the European Parliament

voted in December 2002 against expanding the list of foods that could be irradiated in the 15-nation European Union, pending additional scientific evidence regarding the safety of irradiated foods. Shrimp, frog legs, cereal flakes and several other foods were proposed for addition to the current list, which is limited to spices and seasonings. The EP went so far as to reject a proposal to collaborate with the WHO on research into the safety of irradiated foods.

Further, the EU – citing concerns over 2-ACBs – formally opposed a Codex proposal to remove its 10 kGy maximum dose and allow any food to be irradiated at any dose, no matter how high.²⁷ France, Germany, Japan, the Netherlands, Poland, Sweden, South Korea and the United Kingdom also opposed the proposal. Under this pressure, a key Codex panel in December 2002 abandoned the proposal.²⁸

The decision is significant, to say the least: Codex sets food-safety standards on behalf of more than 160 countries representing more than 90 percent of the world's population. And, Codex standards are enforceable under World Trade Organization (WTO) rules.

If the full Codex Commission ratifies the committee's decision to abandon the proposal and maintain the 10 kGy dose cap, any decision by a WHO member nation to irradiate foods above 10 kGy could be challenged before a WTO tribunal. And, food companies desiring to irradiate their products above 10 kGy may face limitations as to the types of food they could irradiate, or how long irradiated foods could stay on the shelves, be stored, or be shipped.

In retrospect, the 40-plus-year history of analyzing the safety and wholesomeness has been compromised to the extent that a complete reassessment is required in order to protect Americans, as well as millions of people throughout the world where food irradiation is legal, from health risks. This reassessment should take the form of published, peer-reviewed research in the areas of toxicology, food science, radiation chemistry, nutrition and other relevant fields.

Taken together, the well-documented health hazards of irradiated foods; the flawed processes by which food irradiation has been

Questioning Food Irradiation

legalized and endorsed by U.S. and international agencies; the recent caution exhibited by the European Union and the Codex Alimentarius Commission; and the myriad unanswered questions related to this technology, make any proposal to legalize or endorse additional types of food for irradiation, to expand use of irradiation, or to broaden the production and distribution of irradiated foods is ill-advised.

Additional proposals should be withheld, pending the conclusion of research into the toxic properties of 2-ACBs, as well as chemicals known or suspected to cause cancer and birth defects – such as benzene, toluene, ethanol and methyl ethyl ketone – and chemicals that can damage the central nervous system, such as acetone, pentane, heptane, nonane, and ethyl mercaptan.

Notes

- ¹ *Bad Taste: The Disturbing Truth About the World Health Organization's Endorsement of Food Irradiation*. Public Citizen and Grace, Washington, D.C., October 2002.
- ² Bhaskaram, C. and G. Sadasivan. "Effects of feeding irradiated wheat to malnourished children." *American Journal of Clinical Nutrition*, 28:130-135, 1975.
- ³ Jaarma, Maire. "Studies of chemical and enzymatical changes in potato tubers and some higher plants caused by ionizing radiation, including studies on the wholesomeness of $\bar{\alpha}$ -irradiated potato tubers and effects on some carbohydrates in vitro." *Biokemiska institutionen, Kungl. Universitetet i Stockholm*, 1967.
- ⁴ Burnouf, D. et al. "Etude toxicologique transfrontalière destinée à évaluer le risque encouru lors de la consommation d'aliments gras ionisés - Toxikologische Untersuchung zur Risikobewertung beim Verzehr von bestrahlten fetthaltigen Lebensmitteln" – Eine französisch-deutsche Studie im Grenzraum Oberrhein, Rapport final d'étude Interreg II, projet N° 3.171. BFE-R-02-02, Federal Research Centre for Nutrition, Karlsruhe, Germany, 2001.
- ⁵ De, A.K. et al. "Biochemical effects of irradiated sucrose solutions in the rat." *Radiation Research*, 37:202-215, 1969.
- ⁶ Poling, C.E. et al. "Growth, reproduction, survival and histopathology of rats fed beef irradiated with electrons." *Food Res*, 20:193-214, 1955.
- ⁷ Spiher, A.T. "Food irradiation: An FDA report." *FDA Papers*, Oct. 1968.
- ⁸ Reichelt, D. et al. "Long-term animal feeding study for testing the wholesomeness of an irradiated diet with a high content of free radicals." *Federal Research Institute for Food Preservation, Institute for Radiation Technology, Karlsruhe, Germany*, 1972.
- ⁹ Moutschen-Dahmen, M. et al. "Pre-implantation death of mouse eggs caused by irradiated food." *Inter Journ Rad Biol*, 18:201-216, 1970.
- ¹⁰ Anderson, D. et al. "Irradiated laboratory animal diets: Dominant lethal studies in the mouse." *Mutation Research*, 80:333-345, 1981.
- ¹¹ Bugyaki, L., A.R. Deschreider, J. Moutschen, M. Moutschen-Dahmen, A. Thijs, and A. Lafontaine. "Do irradiated foodstuffs have a radiomimetic effect? II. Trials with mice fed wheat meal irradiated at 5 Mrad." *Atompraxis* 14:112-118, 1968.
- ¹² Swaminathan, M.S. et al. "Mutations: Incidence in *Drosophila melanogaster* reared on irradiated medium." *Science*, 141:637-638, 1963.
- ¹³ Shaw, M.W. and Hayes, E. "Effects of irradiated sucrose on the chromosomes of human lymphocytes in vitro." *Nature*, 211:1254-1255, 1966.
- ¹⁴ Kesavan, P.C. and Swaminathan, M.S. "Cytotoxic and radiomimetic activity of irradiated culture medium on human leukocytes." *Current Science*, 16:403-404, 1966.
- ¹⁵ Kesavan, P.C. and Swaminathan, M.S. "Cytotoxic and mutagenic effects of irradiated substrates and food material." *Radiation Botany*, 11:253-281, 1971.
- ¹⁶ "Status of the Food Irradiation Program." *Hearings before the Subcommittee on Research and Development of the Joint Committee on Atomic Energy, Congress of the United States*. July 18/30, 1968. Washington, D.C.: U.S. Government Printing Office.
- ¹⁷ "Evaluation of the health aspects of certain compounds found in irradiated beef." *Life Sciences Research Office, Federation of American Societies for Experimental Biology, Bethesda, Maryland*. Prepared for U.S. Army Medical Research and Development Command, Fort Detrick, Frederick, Maryland, Contract No. DAMD-17-76-C-6055. August 1977. Supplements I and II, March 1979.
- ¹⁸ Stevenson, H. "Identification of irradiated foods." *Food Technology*, 48:141-144, 1994.
- ¹⁹ Burnouf, Op. cit.
- ²⁰ Crone, A.V.J. et al. "Detection of 2-dodecylcyclobutanone in radiation-sterilized chicken meat stored for several years." *International Journal of Food Science and Technology*, 27: 691-696, 1992.
- ²¹ EN 1785. Foodstuffs - Detection of irradiated food containing fat - Gas chromatographic / Mass spectrometric analysis of 2-alkylcyclobutanones. *European Commission*. <www.europa.com>
- ²² Tritsch, G.L. "Food irradiation." *Nutrition*, 16:698-701, 2000.
- ²³ Lofroth, G. "Toxic effects of irradiated foods." *Nature*, 211:302, 1966.
- ²⁴ Schubert, J. "Mutagenicity and cytotoxicity of irradiated foods and food components." *Bulletin of the World Health Organization*, 41:873-904, 1969. (Co-sponsored by the U.S. Atomic Energy Commission and the Food and Drug Administration.)
- ²⁵ Kesavan 1971, Op. cit.
- ²⁶ *A Broken Record: How the FDA Has Legalized – and Continues to Legalize – Food Irradiation Without Testing It for Safety*. Washington, DC: Public Citizen, Global Resource Action Center for the Environment, Cancer Prevention Coalition, October 2000.
- ²⁷ *European Community Comments on CL 2001/34-FAC of the Codex Secretariat. (Proposed Draft Revision to the Codex General Standard for Irradiated Foods, ALINORM 01/12A, paragraph 85 and Appendix VII.)* 4 December 2001.
- ²⁸ Letter from Alicia O. Lustre, Chair, *International Consultative Group on Food Irradiation*, to David Byron, *Food and Agriculture Organization of the United Nations*, 18 November 2002.

Questioning Food Irradiation

Following are many of the dozens of studies conducted since the 1950s that raise questions about the safety of irradiated foods. Most of these studies were conducted at or funded by public agencies, universities and institutes. The excerpts are taken directly from the text of the studies.

Health Problems in Humans [I]

Fifteen children suffering from severe protein-calorie malnutrition...receiving freshly irradiated wheat developed polyploid cells and certain abnormal cells in increasing number as the duration of feeding increased... Though the biological significance of polyploidy is not clear, its association with malignancy makes it imperative that the wholesomeness of irradiated wheat for human consumption be very carefully assessed.

- Bhaskaram, C., and G. Sadasivan. "Effects of feeding irradiated wheat to malnourished children." *Amer Journ Clin Nutr*, 28:130-135, 1975.

Health Problems in Humans [II]

[After eating gamma-irradiated potatoes for 14 weeks], it was evident that the haemoglobin values were significantly higher *during* the period than *before*. The values were also significantly higher *during* than *after*. An additional comparison of the values *before* with the values *after* shows that a small effect still remains.

- Jaarma, Maire. "Studies of chemical and enzymatical changes in potato tubers and some higher plants caused by ionizing radiation, including studies on the wholesomeness of $\bar{\alpha}$ -irradiated potato tubers and effects on some carbohydrates *in vitro*." *Biokemiska institutionen, Kungl. Universitetet i Stockholm*, 1967.

Health Problems in Humans [III]

Ten young men served as test subjects for this study, [and were fed] pork loin which had been ground ... and subjected to gamma radiation... It is apparent...that there may very well be differences in the digestibility of the foodstuffs from irradiated or non-irradiated meat, and in the ability of protein in irradiated or non-irradiated meat to maintain nitrogen balance.

- Plough, I.C. et al. "An evaluation in human begins of the acceptability, digestibility and toxicity of pork sterilized by gamma radiation and stored at room temperature." U.S. Army Medical Nutrition Laboratory, Fitzsimons Army Hospital, Denver. Report No. 204, May 1957.

Health Problems in Humans [IV]

Thirteen young men served as test subjects, [and were fed] an irradiated food diet...of 8 different food items... The excretion of indophenol-reducing substances was significantly higher ($p < .005$) during the irradiated food periods... Irradiation decreased the thiamine and ascorbic acid content and increased the "browning reaction" derivatives, fat soluble carbonyl compounds, and thiobarbituric acid reactants.

- Bierman, E.D. et al. "Short-term human feeding studies of foods sterilized by gamma radiation and stored at room temperature." U.S. Army Medical Nutrition Laboratory, Fitzsimons Army Hospital, Denver. Report No. 224, July 1958.

Chromosomal Aberrations in Human Blood Cells [I]

Irradiated sucrose solutions...were extremely toxic to human lymphocytes. Mitoses were inhibited... Degenerated mitoses were observed and the chromosomes were grossly damaged. The chromatin [DNA]

Questioning Food Irradiation

material was clumped or the chromosomes appeared shattered or pulverized... In contrast, treatment with unirradiated sucrose at the same concentration had no apparent effect on the mitotic rate and the chromosomes were not visibly damaged.

- Shaw, M.W. and Hayes, E. "Effects of irradiated sucrose on the chromosomes of human lymphocytes in vitro." *Nature*, 211:1254-1255, 1966.

Chromosomal Aberrations in Human Blood Cells [II]

Leukocyte cultures from four different healthy human males [underwent] a considerable inhibition of mitosis and chromosome fragmentation. [Additional] research would be extremely prudent.

- Kesavan, P.C. and Swaminathan, M.S. "Cytotoxic and radiomimetic activity of irradiated culture medium on human leukocytes." *Current Science*, 16:403-404, 1966.

A Summary of Problems

Numerous studies have been carried out to ascertain whether cytotoxic effects occur when unirradiated biological test systems are cultured or fed with irradiated media or food. In such studies, adverse physiological (growth retardation and inhibition), cytological (mitotic inhibition and chromosome aberrations) and genetical effects (forward and reverse mutations) have been observed in a wide range of test systems, ranging from bacteriophages to human cells... The available data suggest that [a variety of free radicals] may act as the toxic and mutagenic agents.

- Kesavan, P.C. and Swaminathan, M.S. "Cytotoxic and mutagenic effects of irradiated substrates and food material." *Radiation Botany*, 11:253-281, 1971.

A Thalidomide Warning [I]

The thalidomide disaster might have been prevented if an easily performed investigation of possible cytotoxic effects in plant cells had been made. It must be acknowledged that any compound causing [cellular] damage must be considered a potential hazard to any living cell or cell system – including man.

- Lofroth, G. "Toxic effects of irradiated foods." *Nature*, 211:302, 1966.

A Thalidomide Warning [II]

Irradiating can bring about chemical transformations in food and food components resulting in the formation of potential mutagens, particularly hydrogen peroxide and various organic peroxides... It is now realized, especially since the thalidomide episode, that [older testing] protocols do not detect the more subtle population hazards such as mutagens and teratogens... In view of the serious consequences to the human population which could arise from a high level of induced mutations, it is desirable that protocols for irradiated food should include *in vivo* tests on mammals for possible mutagenicity.

- Schubert, J. "Mutagenicity and cytotoxicity of irradiated foods and food components." *Bulletin of the World Health Organization*, 41:873-904, 1969. (Co-sponsored by the U.S. Atomic Energy Commission and Food and Drug Administration)

A Cancer Warning

An increase in concentration of a mutagen in food by irradiation will increase the incidence of cancer... It will take four to six decades to demonstrate a statistically significant increase in cancer due to mutagens introduced into food by irradiation... When food irradiation is finally prohibited, several decades worth of people with increased cancer incidence will be in the pipeline.

- Tritsch, G.L. "Food Irradiation." *Nutrition*, 16:698-701, 2000.

Toxic Chemicals Formed in Irradiated Food Containing Fat [I]

When food containing fat is treated by ionizing radiation, a group of 2-alkylcyclobutanones is

Questioning Food Irradiation

formed... To date, there is no evidence that the cyclobutanones occur in unirradiated food... *In vitro* experiments using rat and human colon cells indicate that 2-dodecylcyclobutanone (2-DCB)...is clearly cytotoxic and genotoxic... [M]ore experiments than these preliminary ones are required.

- Delincee, H. and Pool-Zobel, B. "Genotoxic properties of 2-dodecylcyclobutanone, a compound formed on irradiation of food containing fat." *Radiation Physics and Chemistry*, 52:39-42, 1998. (Co-sponsored by the International Consultative Group on Food Irradiation.)

Toxic Chemicals Formed in Irradiated Food Containing Fat [II]

In this study, *in vivo* experiments were conducted on rats, which received two different doses of 2-DCB by way of pharyngeal probe... Slight but significant DNA damage was observed in the experimental group that received the higher concentration of 2-DCB (14.9 mg/kg body weight). Further studies are needed to clarify the relevance of these results to an evaluation of risk from the consumption of irradiated foods.

- Delincée, H. et al. "Genotoxicity of 2-dodecylcyclobutanone." *Food Irradiation: Fifth German Conference, Report BFE-R-99-01, Federal Nutrition Research Institute, Karlsruhe, Germany, 1998.*

Toxic Chemicals Formed in Irradiated Food Containing Fat [III]

To date, there is no evidence that 2-alkylcyclobutanones [2-ACB's] occur in unirradiated food, and therefore, it is advisable to determine the toxicological potential... [Human colon tumor cells were incubated with 2-tetradecylcyclobutanone, one particular ACB.] After prolonged incubation times, (1-2 days) at higher concentrations (>50iM), cytotoxicity did appear.

- Delincée, H. et al. "Genotoxicity of 2-alkylcyclobutanones, markers for an irradiation treatment in fat-containing food – Part I: Cyto- and genotoxic potential of 2- tetradecylcyclobutanone." *Radiation Physics and Chemistry*, 63:431-435, 2002.

Unique, Toxic Chemicals Formed in Irradiated Food Containing Fat [IV]

[U]sing an experimental colon carcinogenesis model in rats, 2-ACB's [2-alkylcyclobutanones], when tested at a high concentration, potentiate the effect of an inducing carcinogen on the long term. This was revealed by the increase of colonic neoplastic lesions and the development of a higher number of colon tumours with larger size... This suggests that, in this experiment, 2-ACB's, although they do not induce carcinogenesis, *per se*, rather promote the colonic carcinogenesis process. Finally, it was shown that small fractions of 2-ACB's had been stored in rat adipose tissues and excreted in faeces of the treated rats. This indicates that most of the 2-ACB's is metabolically transformed or stored in other organs...[I]n our opinion further investigations...will help to elucidate a possible risk associated with the consumption of irradiated fat-containing foods.

- Marchioni, E. et al. "Toxicological study to assess the risk associated with consumption of irradiated fat-containing food." (Summary) *International Consultative Group on Food Irradiation, Dec. 2001.*

Radioactivity in Organs and Excrement of Rats

Considerable amounts of radioactivity were present in the liver, kidney, stomach, gastrointestinal tract, and blood serum of rats [fed irradiated sucrose solutions]... Radioactivity was present in urine and feces samples.

- De, A.K. et al. "Biochemical effects of irradiated sucrose solutions in the rat." *Radiation Research*, 37:202-215, 1969.

Fatal Internal Bleeding in Rats [I]

A significant number of rats consuming irradiated beef died from internal hemorrhage within 46 days, the first death of a male rat coming on the 11th day of feeding. This rat became sluggish on the 8th day of the regimen and started refusing food. He continued [to be] morbid during the next two days, did

Questioning Food Irradiation

not eat any food, lost weight and appeared anemic. He was found dead on the 11th day. Post-mortem examination showed hemothorax, the blood had not clotted; there was bleeding also in the epididymis.

- Metta, V.C. et al. "Vitamin K deficiency in rats induced by feeding of irradiated beef." *Journal of Nutrition*, 69:18-21, 1959.
(Co-sponsored by the Surgeon General of the U.S. Army)

Fatal Internal Bleeding in Rats [II]

Hemorrhagic death had occurred in all males fed irradiated diets by day 34... There is evidence to suggest that inefficient absorption of vitamins, i.e. vitamin K, from the intestinal tract may contribute to a deficiency state.

- Mellette, S.J. and Leone, L.A. "Influence of age, sex, strain of rat and fat soluble vitamins on hemorrhagic syndromes in rats fed irradiated beef." *Federation Proceedings*, 19:1045-1048, 1960. (Co-sponsored by the Surgeon General of the U.S. Army)

Fatal Vitamin E Deficiency in Rats

A considerable number of the second litter of the experimental group [of rats that ate irradiated beef] died... Symptoms observed were marked edema of the face, ruffled hair coat, general incoordination, spastic hopping gait, and sometimes complete loss of movement with dragging of the hind quarters. Those pups most severely affected often became completely prostrated a short time before death... In no case were these symptoms noted in the control group... The probability [is that the pups] were suffering from the characteristic muscular dystrophy syndrome (commonly referred to as nutritional muscular dystrophy) known to result from a marginal vitamin E intake.

- Poling, C.E. et al. "Growth, reproduction, survival and histopathology of rats fed beef irradiated with electrons." *Food Res*, 20:193-214, 1955.

Prenatal Deaths in Mice [I]

Freshly irradiated diets produced elevated levels of early deaths in [mice fetuses]... The increase in early deaths would suggest that the diet when irradiated has some mutagenic potential.

- Anderson, D. et al. "Irradiated laboratory animal diets: Dominant lethal studies in the mouse." *Mutation Research*, 80:333-345, 1981.

Prenatal Deaths in Mice [II]

Feeding of mice for two months before mating with 50 percent of the standard complete diet irradiated with [gamma rays] provokes a significant increase of embryonal deaths,... probably to be interpreted as a dominant lethal mutation associated with gross chromosomal aberrations, such as breaks repeatedly found to be induced by irradiated materials.

- Moutschen-Dahmen, M. et al. "Pre-implantation death of mouse eggs caused by irradiated food." *Inter Journ Rad Biol*, 18:201-216, 1970.

Chromosomal Aberrations in Monkeys

The increased incidence of cells with numerical aberrations in animals which received a diet containing freshly irradiated wheat... must be considered significant.... Also, the disappearance of these cells, following the replacement of freshly irradiated wheat with unirradiated wheat, clearly indicates that the appearance of the abnormal cells was due to the ingestion of freshly irradiated wheat.

- Vijayalaxmi. "Cytogenetic studies in monkeys fed irradiated wheat." *Toxicology* 9:181-184, 1978.

Chromosomal Aberrations and Blood Disorder in Rats; Mutations in Mice

[A]n increase of chromosomal aberrations which was significant at the 5 percent level [was observed]... [Later experiments] demonstrated beyond a doubt that this effect is real, and running experi-

Questioning Food Irradiation

ments also indicate an increase of intrauterine foetal death, possibly dominant lethal mutations in the mouse... [A] 15-20 percent decrease of the absolute lymphocyte numbers in the peripheral blood of the rat [was observed]... [T]he lymphopenia produced by irradiated food increased with increasing age of the rats.

- Lofroth, G. et al. "Biological effects of irradiated food. II: Chemical and biological studies of compounds distilled from irradiated food." *Arkiv. Zool.* 18:529-547, 1966.

Chromosomal Aberrations in Mice

Feeding of freshly irradiated wheat resulted in significantly increased incidence of polyploidy cells in bone marrow, aneuploid cells in testis, reduction in number of spermatogonia...as well as a higher mutagenic index... [S]ome toxic substance(s) may be formed during irradiation.

- Vijayalaxmi."Genetic effects of feeding irradiated wheat to mice." *Canadian Journal of Genetics and Cytology*, 18:231-238, 1976.

Chromosomal Aberrations in Rats

Feeding irradiated wheat to rats was associated with an increase in the number of polyploid cells in the bone-marrow... Irrespective of the protein content in the diet, animals which received irradiated wheat had polyploid cells in their bone-marrow.

- Vijayalaxmi and G. Sadasivan. "Chromosomal aberrations in rats fed irradiated wheat." *Inter Journ Rad Biol*, 27:135-142, 1975.

Chromosomal Aberrations in Hamsters

The proportion of [bone marrow] cells with polyploidy increased between 4 to 5 times the control level... When feeding of the irradiated diet stopped, the proportion of polyploid cells returned to the control level.

- Renner, H.W. "Chromosome studies on bone marrow cells of chinese hamsters fed a radiosterilized diet." *Toxicology*, 8:213-222, 1977.

Genetic Damage in Rats

Well-fed rats, when switched over to a diet of irradiated wheat, showed a higher mutagenic index than those given unirradiated wheat.

- Vijayalaxmi and K.V. Rao. "Dominant lethal mutations in rats fed on irradiated wheat." *Inter Journ Rad Biol*, 29:93-98, 1976.

Immune Dysfunction in Rats

Rats given diets containing freshly irradiated wheat showed significantly lower mean antibody titres to four different antigens, decreased numbers of antibody-forming cells in the spleen and rosette-forming lymphocytes... [T]he consumption of irradiated wheat is associated with changes in the immune status of the animal.

- Vijayalaxmi. "Immune response in rats given irradiated wheat." *British Journal of Nutrition*, 40:535-541, 1978.

Immune Dysfunction in Hamsters

The irradiated fish diet has apparently caused an even greater immunological response than unirradiated fish... [T]he possibility of a mutagen remaining undetected must be considered.

- Renner, H.W. et al. "An investigation of the genetic toxicology of irradiated foodstuffs using short-term test systems. III - In vivo tests in small rodents and in *Drosophila melanogaster*." *Food Chemistry and Toxicology*, 20:867-878, 1982.

Reproductive Dysfunction, Cancer, Stunted Growth in Mammals

A careful analysis by FDA of all [Army] data present (including 31 looseleaf notebooks of animal

Questioning Food Irradiation

feeding test results) showed significant adverse effects produced in animals fed irradiated food... What were these adverse effects?... A decrease of 20.7 percent in surviving weaned rats... A 32.3 percent decrease in surviving progeny of dogs... Dogs weighing 11.3 percent less than animals on the control diets... Carcinomas of the pituitary gland, a particularly disturbing finding since this is an extremely rare type of malignant tumor.

- Spiher, A.T. "Food irradiation: An FDA report." *FDA Papers*, Oct. 1968.

Reproductive Dysfunction in Rats [I]

Very high losses of litter in the [first] and [second] generations [80 and 85 percent, respectively] in spite of a high fertility rate and normal size of litter in all dietary groups caused at first great difficulty. The suspicion that the animals had obtained too little vitamin E was certified correct.

- Reichelt, D. et al. "Long-term animal feeding study for testing the wholesomeness of an irradiated diet with a high content of free radicals." *Federal Research Institute for Food Preservation, Institute for Radiation Technology, Karlsruhe, Germany, 1972.*

Reproductive Dysfunction in Rats [II]

An impairment in the fertility of the male and an increased mortality in litters, which [researchers] believed was due to vitamin E destruction.

- DaCosta, E. and Levenson, S.M. "Effect of diet exposed to capacitor irradiation on the growth and fertility of the albino rat." *U.S. Army Medical Nutrition Laboratory, Fitzsimons Army Hospital, Denver. Report No. 89, 1951. Cited in Kraybill, H.F. and Huber, T.E. "The wholesomeness of irradiated food and its military implications." Paper to be presented at 63rd Annual Convention, Association of Military Surgeons, United States of America, Hotel Statler, Washington, D.C., Nov. 12-14, 1956.*

Reproductive Dysfunction in Mice [I]

Cytogenic examinations of the developing spermatogonia in 30 mice of each group revealed that cytogenetic abnormalities were significantly more frequent in the group fed irradiated flour than in the control group... [T]he incidence of litters [with non-viable offspring] was significantly higher in the group fed irradiated flour... [O]n the average the losses [of young mice] were about 35% higher in the test group than in the controls. The life span of mice fed irradiated flour was slightly shorter than in the control mice.

- Bugyaki, L., A.R. Deschreider, J. Moutschen, M. Moutschen-Dahmen, A. Thijs, and A. Lafontaine. "Do irradiated foodstuffs have a radiomimetic effect? II. Trials with mice fed wheat meal irradiated at 5 Mrad." *Atompraxis* 14:112-118, 1968.

Reproductive Dysfunction in Mice [II]

The mice raised on the irradiated diet exhibited some impairment in lactational performance.

- Luckey, T.D. et al. "Nutritional adequacy of a semi-synthetic diet sterilized by steam or cathode rays." *Food Research*, 20(2):180, 1955. Cited in Kraybill, H.F. "Problems in food processing by ionizing radiations with special reference to wholesomeness studies on irradiated foods." Paper to be presented at Fifth Annual Conference sponsored by Pennsylvania Public Health Association, Pennsylvania Health Council, Medical Society of Pennsylvania, Pennsylvania Department of Health, held at Pennsylvania State University, University Park, Pennsylvania, August 21, 1956.

Reproductive Dysfunction in Fruit Flies

The production of *Drosophila* offspring in cultures containing gamma irradiated chicken meat was much lower... The production...was not increased by changing the basal medium or by adding a vitamin supplement.

- Raltech Scientific Services Inc., Madison, Wisconsin. "Final Report: Evaluation of the mutagenicity of irradiated sterilized chicken by the sex-linked recessive lethal test in *Drosophila melanogaster*." Contract DAMD 17-76-C-6047, submitted to U.S. Army Medical Research and Development Command, Fort Detrick, Frederick, Maryland. June 15, 1979.

Questioning Food Irradiation

Mutations in Fruit Flies [I]

An increase in the rate of mutation has been found in *Drosophila melanogaster* reared on a basic medium that was irradiated with a sterilizing dose (150,000 rads) of cobalt-60 gamma rays... Visible changes were two to six times more frequent in the irradiated series than in the controls,...[such as] half-thorax, vestigial wings and incurved wings.

- Swaminathan, M.S. et al. "Mutations: Incidence in *Drosophila melanogaster* reared on irradiated medium." *Science*, 141:637-638, 1963.

Mutations in Fruit Flies [II]

[S]everal experimental variables in culture medium may be associated with increased mutation frequencies in *Drosophila*; namely irradiated whole food... The increased mutation frequencies associated with flies cultured on aged food implies that the [toxic products] are long lived.

- Rinehart, R.R. and Ratty, F.J. "Mutation in *Drosophila melanogaster* cultured on irradiated whole food or food components." *Intern Journ Rad Biol*, 12(4):347-354, 1967.

Mutations in Fruit Flies [III]

There was an approximate twofold increase in sex-linked recessive lethality [in *Drosophila melanogaster* cultured in irradiated medium]. This increase can be attributed largely to an increase in gonial mutants.

- Rinehart, R.R. and Ratty, F.J. "Mutation in *Drosophila melanogaster* cultured on irradiated food." *Genetics*, 52(6):1119-1126, 1965.

Mutations in Fruit Flies [IV]

[A] small but constant increase in sex-linked and autosomal recessive lethal frequencies [was observed in *Drosophila melanogaster* cultured in irradiated medium]... A linear relationship of dose and effect was obtained with regard to dominant lethals.

- Kesavan, P.C. and Swaminathan, M.S. "Mutagenic effects of irradiated culture media in *Drosophila melanogaster*." *Indian Journal of Genetics*, 29:173-183, 1969. Cited in Kesavan, P.C. and Swaminathan, M.S. "Cytotoxic and mutagenic effects of irradiated substrates and food material." *Radiation Botany*, 11:253-281, 1971.

Stunted Growth of Rats

In general, the irradiated foods produced a depressed growth rate... The effect of the radiation variable is significant... Higher intake coupled with the lower growth rates of rats on the rations containing irradiated carrots resulted in a lower [food] efficiency.

- Tinsley, I.J. et al. "The growth, reproduction, longevity, and histopathology of rats fed gamma-irradiated carrots." *Toxicology and Applied Pharmacology*, 16:306-317, 1970.

Mutations in Salmonella

Groups of Swiss albino mice (SPF) fed with normal and gamma-irradiated food at doses of 0.75, 1.5, and 3.0 Mrad, were injected intraperitoneally with *Salmonella typhimurium* TA 1530 for the host mediated assay test of mutagenesis. The results indicate that there is a significant increase in mutation frequency induced by the 3 Mrad sterilized food.

- Johnston-Arthur T., M. Brena-Valle, K. Turanitz, R. Hruby, and G. Stehlik. "Mutagenicity of irradiated food in the host mediated assay system." *Studia Biophysica*, (Berlin), 50:137-141, 1975.

