Some Examples of Successful Applications in Food Irradiation

Poultry

- **Purpose:** - Eliminate *Salmonella* (and other pathogens, e.g. *Listeria, Campylobacter)*
  - Extend shelf-life
  - Maintain nutritional adequacy and quality
  - Safety

- **Benefits:** Low doses required to eliminate pathogens of concern and for shelf-life extension

- **Market Size:** Large component of meats consumed in the world, and increasing at the expense of other meats. Thus expanding market

- **Economical Advantage:** Large volume, low cost, significant health benefit

Poultry (contd)

- Quality: Good
- Industry: Appears interested
- Customer Need: Accute awareness of *salmonella* hazard
- Technical Advantage: Current control measures against *Salmonella* contamination not adequate because of multicomponent system
- Regulation/Clearance:
  - In USA up to 3 kGy (1992)
  - In many parts of Europe (3-7 kGy)
  - In Thailand up to 7 kGy (1986)
  - Application submitted in Canada (3 kGy)

Doses for Poultry Irradiation

(i) < 5 kGy for elimination of pathogens like *Salmonella, E. Coli* O157:H7, *Campylobacter*, (radicidation) and control of spoilage microorganisms (radurization)

- Product requires refrigeration

(ii) > 10 kGy for sterilization (radappertization)

- No refrigeration required
- Heat-inactivation of enzymes required

Some Typical Approved Doses

Type	Country	Purpose	Dose (kGy)
Chicken	Bangladesh	DC/SL[1]	8
Poultry	Brazil	DC/SL	7
Chicken	Chile	DC	7
Mechanically Deboned Chicken	France	DC	5
Poultry	Israel	DC/SL	7
Poultry	Netherlands	DC/SL	7
Chicken	Syria	DC/SL	7
Chicken	Thailand	DC/SL	7
Chicken	USA	DC/SL	3

[1] DC, Decontamination; SL, shelf-life

Levels of *Salmonellae* in the Canadian Poultry Industry[a]

Source	% Level
Breeder day-old chicks	20-25%
Hatchery supply flocks	50%
Hatcheries	5%
Broiler farms	55%
Rendered product	20-30%
Mixed feeds	6%
Poultry crates	60%
Chicken carcasses at the processors	50-60%
Turkery carcasses at the processors	60%

[a] Data taken from *Salmonella* Coordinating Unit Report (1981)

Measures Suggested or Used for *Salmonella* Control in Poultry

- Poultry contamination can arise from many sources along the chain, from hatching to processing

1. Chlorine Treatment
   - Toxic chlorogenic compounds possible
   - Does not completely eliminate *Salmonella*
   - 200 mg/kg (10 min), 10^5 cells/mL, 95% reduction
   - 45 mg/kg can cause
     - Eye irritation
     - Whitish chicken skin appearance
   - US allows 20 mg/kg, at industry's discretion

Measures Suggested or Used for *Salmonella* Control in Poultry (contd)

2. Acetic Acid (0.1 to 0.2%)
   - Reduces *Salmonella*
   - Causes skin discoloration
3. Heat
   - Leads to partially cooked product
4. Irradiation
   - Eliminates or otherwise inactivates, *Salmonella* and other pathogenic microorganisms present in poultry and hamburger, (thereby, making these foods safer for human consumption)
   - An additional benefit is the extension of shelf-life of poultry and hamburger by reducing the microbial population, primarily vegetative forms of bacteria, which are the cause of the spoilage
   - It is generally a cold process

Irradiation (contd)

- Work from several labs shows that for the low numbers of *salmonellae* cells generally contaminating chicken and chicken meat, 2.5 kGy dose is sufficient to eliminate *salmonellae* from fresh meat and 5 kGy from frozen meat
- *Campylobacter jejuni, Staphylococcus aureus, Yersinia enterocolitica and E. coli* all have higher sensitivity to radiation than *salmonellae* and therefore are eliminated at 2.5 kGy dose
- *Listeria monocytogenes* if present in very large numbers (>10^5 cfu/g) requires higher than 2.5 kGy dose for complete elimination from raw chicken
- Although proper cooking takes care of *salmonella* (and other pathogens) the majority of the cases are due to cross-contamination from raw poultry. There seems to be no other simple and effective method to control *salmonellae*, than irradiation

D_{10}-Values[a] of *E. Coli* O157:H7 in Chicken

Temp (°C)	D_{10}-Values (kGy)
5	0.27
-5	0.42

[a] The D_{10}-Value is defined as the dose of radiation required to reduce the number of colony-forming units by 90%

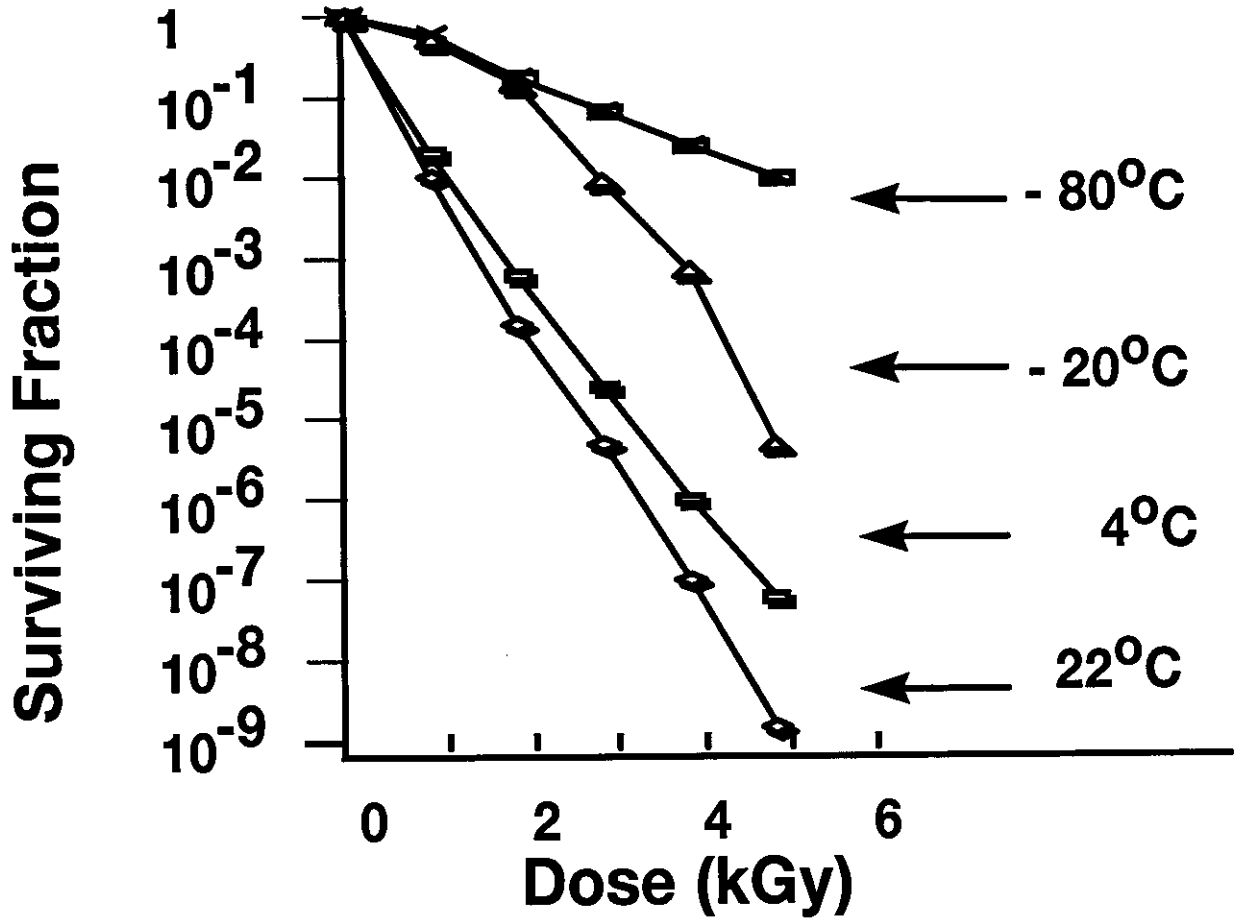
Log Reduction in the Number of Viable Cells of Different *Salmonella* Species on Irradiation (5 kGy) of Poultry Meat at 22°C

Organisms	Log Reduction
S. anatum	12
S. enteritidis	17
S. give	13
S. heidelberg	13
S. infantis	15
S. organienburg	10
S. pullorum	10
S. senftenberg	15
S. typhimurium	10
S. worthington	10

From Idziak and Incze, 1968

- Very similar values have been obtained for some of these organisms in hamburger

Effect of Temperature



Radiation survival curves for *S.typhimurium,* RIA.The cells were inoculated onto chicken before irradiation (Previte et al.,1970)

Amino Acid Analyses of Irradiated and Unirradiated Chicken, Stored for 6 Days at +5°C and Cooked

Amino Acid	0 kGy	3 kGy	6 kGy
	(g/100g protein)		
Isoleucine	4.2	4.2	4.3
Leucine	6.7	6.7	6.8
Lysine	7.1	6.9	7.1
Methionine	2.3	2.3	2.35
Cystine	0.98	1.02	1.02
Phenylalanine	3.6	3.5	3.5
Tyrosine	2.9	2.8	3.0
Threonine	4.0	4.0	4.1
Tryptophan	0.98	0.93	0.96
Valine	4.8	4.8	4.9
Arginine	6.6	6.5	6.6
Histidine	3.4	3.3	3.3
Alanine	6.4	6.5	6.6
Aspartic acid	8.4	8.2	8.4
Glutamic acid	13.6	13.6	13.6
Glycine	8.5	8.8	9.0
Proline	5.5	5.6	5.7
Serine	4.1	4.1	4.2

Singh (1988)

- No significant changes in amino acids in chicken proteins, on irradiation and cooking

Nutritive Value of Protein in Irradiated Chicken Meat Stored at 5°C Before Cooking[1]

Dose (kGy)	Protein Efficiency Ratio[2]
0	2.18
3	2.34
6	2.21

[1] Singh (1988)
[2] Protein efficiency ratio is the weight (grams) gained by rats per gram of protein consumed

- At the radiation doses required for poultry, there is no significant effect on the protein efficiency ratio

Vitamin Losses Due to Radiation Pasteurization of Chicken Breasts Impact on Human Diet (American)

Thiamin	Riboflavin	Niacin
0.1%	0%	0%

Fox et al. Int. J. Radiat. Biol. 55(4), 689-703, 1989
(Radiation dose 1 kGy at 0°C)

- In light of the contribution of chicken in the American diet to the overall intake of these vitamins, the loss of thiamin is not very significant

Effect on Vitamins

Effect of irradiation on vitamins in chicken analysed after storage for 4-7 days at 5°C, followed by cooking

Vitamin	Initial amount present	Dose (kGy) 3 % change	6 % change
Thiamin, B_1	0.5 mg/kg (10)[b]	0.0	-30
Riboflavin, B_2	2.6 mg/kg (12)	+31.6	+4
Niacin, B_5	60 mg/kg (160)[c]	0.0	-15
Pyridoxine, B_6	1.4 mg/kg (10)	+21.4	+7
Cyano-cobal-amine, B_{12}	25 µg/kg (10)	+56	+56
Folic acid	0.3 mg/kg (1.95)	0.0	-33.3
Pantothenic acid	9 mg/kg (50)	+133	+66.6
Retinol, A	1400 IU/kg (870)	+57	+36
Tocopherol, E	2.6 mg/kg (70)[d]	-38	-38

(Singh, 1988)

[a] One of the two sets of data given by the authors; [b] numbers in parenthesis are the recommended nutrient intake given as mg or µg/kg (corresponding to the intital amount present); [c] as meq/kg; [d] as µg/kg

Changes in Odour of Irradiated and Unirradiated Chicken Carcasses Stored at 1.6°C[a]

Storage Time (d)	Unirradiated Control	Irradiation Dose	
	0 kGy	2.5 kGy	5 kGy
0	Fresh chicken	Slight irrad odour	Irrad odour
4	Fresh chicken	Fresh chicken odour	Slight irrad odour
8	No odour	Fresh chicken odour	Fresh chicken odour
11	Slight off-odour	Chicken odour	Chicken odour
15	Putrid	Slight chicken odour	Slight chicken odour
18	Putrid	Stale chicken odour	Stale chicken odour
22	Putrid	Stale chicken odour	Stale chicken odour
31	Putrid	Stale chicken odour	Stale chicken odour

[a] Based on data of Kahan and Howker (1978)

Irradiation Odour

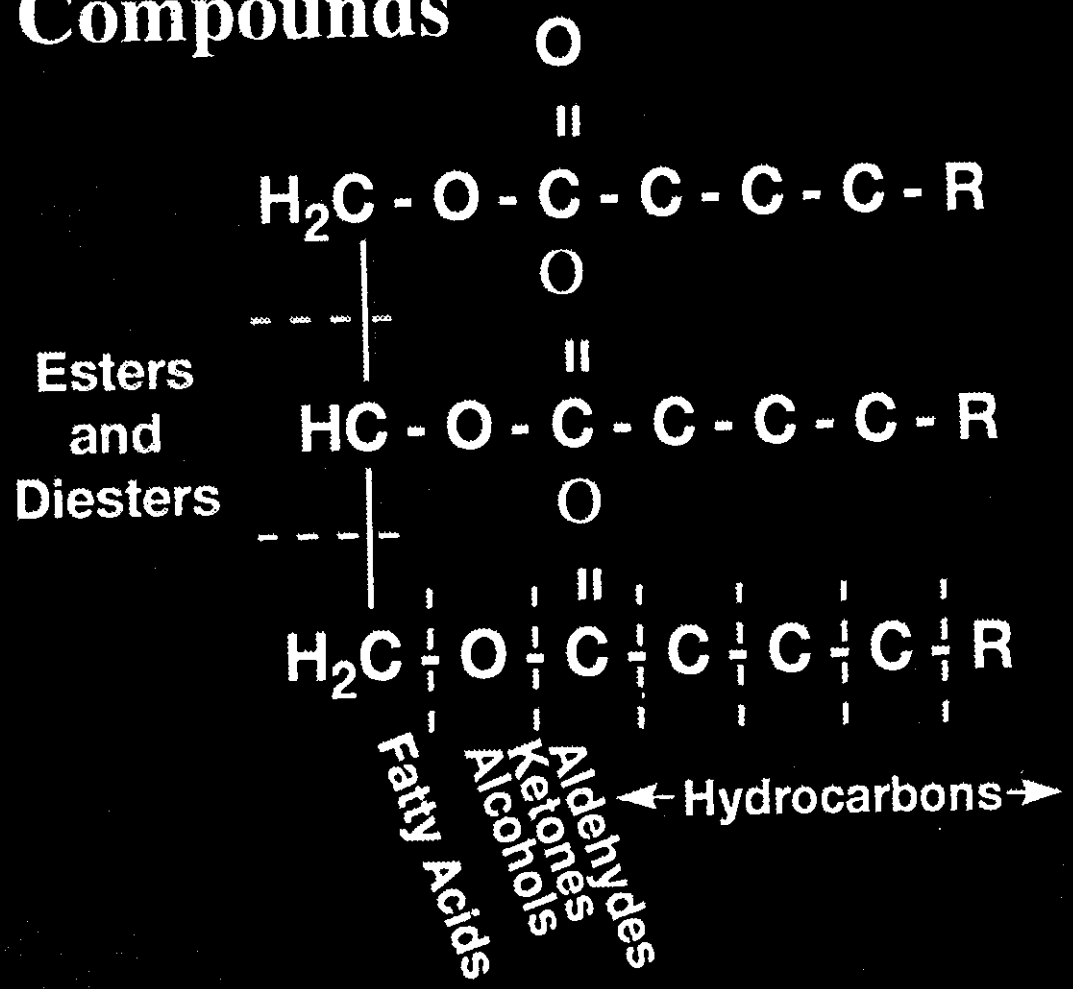
- It resembles scorching but has also been referred to in other more descriptive terms as
  - Goaty
  - Wet dog
- Appearance of irradiation odour has different threshold for different foods

Suggested Volatile Components of Irradiation Odour in Beef

Irradiation		Retort
Merritt, 1966 (GC/MS)	Wicks et al. 1967 (CS/MS, Sniffing)	Brennen, 1964 (GC)
Methyl Mercaptan Ethyl Mercaptan Isobutyl Mercaptan Dimethyl Sulfide	Methyl Mercaptan Nonanal Phenyl Acetaldehyde	Propyl Mercaptan Butyl Mercaptan

- Doty (1955) suggested that irradiation odour can be removed by removal of sulfur compounds

Volatile Compounds



Yield of Major Radiolysis Products in Chicken as a Function of Dose[a]

	Dose (kGy at -30°C)			
Compound	0	30	60	90
Group 1	μg/kg of Meat			
Pentane	110	176	246	356
Hexane	00	67	159	221
Heptane	21	86	268	428
Octane	25	49	182	225
Pentene	35	52	81	119
Hexene	5	28	53	77
Heptene	6	52	161	240
Octene	5	45	85	119
Group 2	μg/kg of Fat			
Pentadecane	0	6	26	35
Heptadecene	0	26	52	65
Heptadecadiene	0	25	41	55
Hexadecanal	0	50	60	110
Dihexadecanoyl propanedioldiester (1,2)	0	10	30	55
Hexadecanoyl octadecenoyl propanedioldiester (1,2)	0	20	65	80

[a] Data taken from Merritt et al. (1985); average of duplicate determinations

Volatile Compounds (Contd)

- These volatiles are generally present at ppm to ppb (mg to μg/kg) levels
- Volatiles, such as aldehydes and ketones, impart particular flavours to foods, which increase with irradiation dose
- Some minor volatile products, not detected in unirradiated but detected in irradiated samples, have been suggested as markers of irradiated chicken, e.g., 2- dodecyl cyclobutanone, and hydrocarbons

Safety of Irradiated Chicken

- A major feeding study on radiation sterilized chicken meat was initiated by the U.S. Army in 1976 at Raltech Scientific Services Inc. in St. Louis, Missouri
- Results of the Raltech study were reviewed by an expert committee which concluded that there was no evidence of genetic toxicity or teratogenic effects in mice, hamsters or rabbits due to the ingestion of the meat
- Nor was there definitive evidence of toxicological effects in mammals in multigeneration studies with mice and dogs
- The committee thus recommended that the irradiated meat was wholesome and safe
- In a Chinese study, young male human volunteers fed for over 15 days with 3 month old irradiated (25 to 40 kGy) chicken stored at room temperature, showed no clinical abnormalities

Conclusions

- Overall, the irradiation of chicken at doses less than 8 kGy (at 1 to 5°C) offers the potential of increasing the shelf-life of fresh chicken (storage at 1 to 5°C) by a factor of ~2 with the sensory qualities being excellent at a dose of 2.5 kGy and acceptable up to a dose of ~8 kGy

- The microbiological shelf-life of fresh chicken carcass or deboned chicken meat (6 to 11 d) is extended by a factor of 2 to 4 on irradiation to a dose of 2.5 kGy followed by storage between 1 and 4°C

Conclusions (contd)

- Irradiation of fresh chicken carcasses, pieces, or deboned chicken meat with a dose of 2.5 kGy seems to be sufficient to eliminate naturally occurring *Salmonella* contamination, which is generally present in North America in extremely low numbers (1 to 3 cells/100g)
- For elimination of *Salmonella* in frozen chicken, doses higher than 2.5 kGy (≤5 kGy) are required
- The 2.5 kGy dose also appears to be sufficient to eliminate or control other bacterial pathogens such as *Campylobacter jejuni, Yersinia enterocolitica and E. coli* O157:H7