

Ioannis S. Arvanitoyannis



# Irradiation of Food Commodities

Techniques, Applications, Detection,  
Legislation, Safety and Consumer Opinion



# ***Irradiation of Food Commodities: Techniques, Applications, Detection, Legislation, Safety and Consumer Opinion***

Ioannis S. Arvanitoyannis



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*Irradiation of Food Commodities:  
Techniques, Applications, Detection, Legislation,  
Safety and Consumer Opinion*

***This book is dedicated to***

*my beloved and precious wife for her unfailing support and encouragement throughout a too long time of continuous pressure and for waiting for my “lost spare time” and to my three children,*

- *Iasson (the oldest and the most sentimental)*
- *Artemis-Eleni (the mindful)*
- *Nefeli-Kallisti (the youngest and the most sociable)*

*who do not fail one single day to embellish our lives.*

*And to the memory of my grandparents, whose moral support in the early stages of my life was crucial for the rest of it.*

**—Ioannis S. Arvanitoyannis**

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## *Preface*

Since the early beginnings of their presence on Earth, humans have tried to prolong the shelf life of foods they collect or hunt. Among the first approaches to preservation of foods of animal origin was cooking, smoking, and freezing. However, the increase in population augmented the demands for shelf life prolongation, thereby requiring the introduction of novel techniques. Among the relatively recent techniques (high pressure, microwave heating, ohmic heating, UV irradiation, pulsed electric field pasteurization, etc.), irradiation in its many forms ( $\gamma$ -irradiation, microwave, UV, and electron beam) has gained ground at the expense of the already applied conventional techniques. Although reservations and doubts have been expressed both by scientists and by consumer movements/organizations regarding the usage of irradiation, the current opinion is that its employment has more advantages than disadvantages. On the other hand, the disadvantages can be substantially reduced if extra care is taken during the applied irradiation processes to ensure the usage of the appropriate irradiation dose and time and to minimize the possibility of irradiation leakage. There has been a “confrontation” between the European Union (EU) and the United States regarding legislation referring to labeling of irradiated foods. Similarly to genetically modified organisms and genetically modified foods, the EU adopted two directives—Directive 1999/2/EC concerning foods and food ingredients treated with ionizing radiation and Directive 1999/3/EC on the establishment of a community list of foods and food ingredients treated with ionizing radiation—in an attempt to eliminate or at least minimize the differences among the various EU member states. Labeling of the irradiated foodstuff is required for any food that has been subjected to irradiation either within the EU or outside the EU but that will be imported into it. In view of the continuously increasing interest in identifying irradiated foods, there has been strong emphasis on developing novel, rapid, reliable, and validated detection methods. In fact, 10 methods have been validated and approved as EN standards (EN 1784:1996, EN 1785:2003, EN 1786:1996, EN 1787:2000, EN 1788:2001, EN 13708:2001, EN 13751:2002, EN 13783:2001, EN 13784:2001, and EN 14569:2004). However, one should consider these standards as part of a dynamic process because in practice there has been a strong need for introducing modifications to improve their effectiveness and avoid potential interferences. A plethora of research articles have been published on applications

of irradiation detection methods covering a wide range of foods. Occasionally, two or more methods have been applied simultaneously for testing comparatively the effectiveness of methods. One important finding of the comparative studies is that methods such as electron spin resonance, thermoluminescence, and DNA comet assay are the most reliable, rapid, and promising methods.

This book comprehensively covers most of the aspects of food irradiation, such as irradiation equipment, food packaging materials for irradiation, applications of irradiation to all foods of plant and animal origin, irradiation detection methods, legislation issues, and consumer behavior with regard to irradiated foods. The book is divided into the following parts:

Part A: Legislation

Part B: Irradiation Techniques and Materials

Part C: Irradiated Food: Detection and Risk Assessment

Part D: Applications of Irradiation on Foods of Animal Origin

Part E: Applications of Irradiation on Foods of Plant Origin

Part F: Other Applications of Irradiation

Part G: Consumer Opinion

The aim of this book is to provide updated information on irradiation treatment, a technique that is gradually gaining ground, by thoroughly discussing all important issues, referring extensively to the literature. It is noteworthy that this book contains a large number of comprehensive tables, informative figures, and references.

This book is addressed to a wide audience, including food scientists and technologists, agriculturists, food chemists, microbiologists, veterinary doctors, academics (professors and researchers involved in food technology and food safety), industrialists, and, in general, anyone who would like to gain insight into the current situation/utilization of irradiation, either alone or in conjunction with other techniques, for food preservation.

—Ioannis S. Arvanitoyannis



# Abbreviations

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Abbreviation	Full Name
%E	Percentage elongation at break
%UE	Ultimate percentage elongation
2-ACBs	2-Alkylcyclobutanones
2-AF	2-Aminofluorene
2-DCB	2-Dodecylcyclobutanone
8-MOP	8-Methoxypsoralen
2-TCB	2-Tetradecylcyclobutanone
2-TDCB	2-Tetradecenylcyclobutanone
1,3-DTBB	1,3-Di- <i>tert</i> -butylbenzene
2,4-DTBP	2,4-Di- <i>tert</i> -butylphenol
<b>A</b>	
AA	Ascorbic acid
AAC	Apparent amylose content
AAc	Acrylic acid
AAm	Acrylamide
ACBs	2-Alkylcyclobutanones
ACC	1-Aminocyclopropane-1-carboxylic acid
ACPY	2-Acetyl-1-pyrroline
AD	Additive dose
AFM	Atomic force microscopy
AN	Acid number
AO	Acridine orange
APC	Aerobic plate count
AR	Aminoreductone
AU	Allylurea
AUDPC	Area under the disease progress curve
$a_w$	Water activity
<b>B</b>	
$\beta$ -LG	$\beta$ -Lactoglobulin
BAs	Biogenic amines
BEUC	Bureau Européen des Unions des Consommateurs
BF	Back fat
BHT	Butylated hydroxytoluene
BLG	Bovine $\beta$ -lactoglobulin
BMA	British Medical Association
BOPP	Biaxially oriented polypropylene
BP	Benzophenone
BSA	Bovine serum albumin

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(Continued)

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<b>Abbreviation</b>	<b>Full Name</b>
<b>C</b>	
CA	Water contact angle
CaA	Calcium ascorbate
CAS	Calcium caseinate
CAS:WP	Caseinate-whey protein
CC	Cotton cellulose
CCFAC	Codex Committee on Food Additives and Contaminants
CD	Circular dichroism
CEg	Consumers in Europe Group
CEN	European Committee for Standardisation
CEN/TC 275	Technical Committee
CFPDC	Consolidated Forms and Publications Distribution Center
CFR	Code of Federal Regulations
CFU	Colony-forming units
CGCD	Computerized glow curve deconvolution
CGP	Coated with pectin-based materials containing 0.5% green tea powder
CH	Conventional heating
CHDM	1,4-Cyclohexane dimethanol
CHO	Chinese hamster ovary
CIPC	Chlorophenyl isopropyl carbamate
<i>cis</i> -2dDeCB	<i>cis</i> -2-(dodec-5'-enyl)-cyclobutanones
<i>cis</i> -2-tDeCB	<i>cis</i> -2-(tetradec-5'-enyl)-cyclobutanones
CMC	Carboxymethyl cellulose
CM-chitosan	Carboxymethylated chitosan
CMS	Carboxymethyl starch
CO	Corn oil
CON	Concentrate
CP	Coated with pectin-based materials
CP	Crude protein
CPA	Cyclopiazonic acid
CPP	Cast polypropylene
CPV	Cool pasting viscosity
CR	Concentration ratio
CS	Cobalt stearate
CS	Canola seed
CSMA	Cobalt styrene maleate copolymer
CTA	Cellulose triacetate
CTS	Chitosan
C-XANES	X-ray absorption near edge spectroscopy
CZ	Corn zein
<b>D</b>	
d <sub>4</sub> -Furan	Deuterated furan
DAA	Dehydroascorbic acid
DAE	Dimethylacetamide-acetone-ethanol
DD	Deacetylation
DEFT	Direct epifluorescent filter technique
DEHP	Ethylhexyl phthalate

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(Continued)

Abbreviation	Full Name
DEHP	Di(2-ethylhexyl)phthalate
DFD	Dark, firm, dry
DGC	Dry gluten content
DHP-chitosan	Dihydroxypropyl-chitosan
DM	Dry matter
DNA	Deoxyribonucleic acid
DON	Deoxynivalenol
DP	Degrees of polymerization
DPPH	1,1-Diphenyl-2-picrylhydrazyl
DPPH	2,2-Diphenyl-1-picrylhydrazyl
DS	Degree of substitution
DSC	Differential scanning calorimetry
DSE	Direct solvent extraction
<b>E</b>	
EA	Egg albumin
EB	Electron beam, e-beam
ELISA	Enzyme-linked immunosorbent assay
EO	Ethylene oxide
EPR	Electron paramagnetic resonance
ERA	Ecological risk assessment
ESD	Experimental sterilizing dose
ESR	Electron spin resonance
Euro Coop	European Community of Consumer Co-operatives
EVOH	Ethylene vinyl alcohol
<b>F</b>	
FAO	Food and Agriculture Organization
FCC	Florisil column chromatography
FDA	U.S. Food and Drug Administration
FFA	Free fatty acid
FI	Fusarium-infected
FO	Flaxseed oil
FRAP	Ferric reducing antioxidant power
FSA	Food Standards Agency
FSI	Food Safety Information Centre
FSIS	Food Safety and Inspection Service
FSO	Food Safety Objective
FT-IR	Fourier transform infrared spectroscopy
FTR	Fourier transform Raman spectroscopy
<b>G</b>	
GAP	Good agricultural practices
GC	Gas chromatography
GM	Genetically modified
GMO	Genetically modified organism
GMP	Good manufacturing practice
GPC	Gel permeation chromatogram
GPC	Gel permeation chromatography

(Continued)

<b>Abbreviation</b>	<b>Full Name</b>
GRAS	Generally recognized as safe
GS	Grape seed
GT	Green tea
<b>H</b>	
HACCP	Hazard analysis critical control point
HAV	Hepatitis A virus
HEMA	2-Hydroxyethyl methacrylate
HESI	Health and Environmental Sciences Institute
HF	Hyperfine
HPLC	High-performance liquid chromatography
HPMC	Hydroxypropyl methylcellulose
HPSEC-MALLS-RI	High-performance size-exclusion chromatography equipped with multiangle laser-light scattering and refractive index
HPV	Hot pasting viscosity
HRGC	High-resolution gas chromatography
HSP	Hydrochloride-soluble pectin
<b>I</b>	
IAEA	International Atomic Energy Agency
ICGFI	International Consultative Group on Food Irradiation
IgE	Immunoglobulin E
ILSI	International Life Sciences Institute
IM	Intermediate moisture
IR	Infrared
IR-H treatments	Irradiation followed by heat treatments
IV	Iodine value
IVPD	<i>In vitro</i> protein digestibility
<b>J</b>	
JECFA	Joint Food and Agriculture Organization/World Health Organization Expert Committees on Food Additives
<b>L</b>	
LBG	Locust bean gum
LD	Lethal dose
LDPE	Low-density polyethylene
LDPEL	Low-density polyethylene laminate
LET	Linear energy transfer
LEW	Liquid egg white
LEY	Liquid egg yolk
linac	Linear accelerator
LLDPE	Linear low-density polyethylene
LOD	Limit of detection
LoDIF	Low dose rate irradiation facility
LODs	Limits of detection
LOOH	Lipid hydroperoxides
LPA	Low phytic acid

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(Continued)

Abbreviation	Full Name
LPD	Lag phase duration
LWE	Liquid whole egg
<b>M</b>	
MAP	Modified atmosphere packaging
MCGC	Moisture of wet gluten content
MDCM	Mechanically deboned chicken meat
MeBr	Methyl bromide
MEHP	Mono(2-ethylhexyl)phthalate
MetMb	Metmyoglobin
MF	Mutant frequency
MG	Molds growth
MN	Micronucleus
MPD	Maximum population density
MRC	Mechanically recovered chicken
MRM	Mechanically recovered meat
MS	Mass spectrometry
MTG	Microbial transglutaminase
$M_v$	Viscosity average molecular weight
MW	Microwave
MW	Microwave cooking
$M_w$	Weight average molecular weight
MWI	Microwave irradiation
MYC	Mold and yeast counts
<b>N</b>	
NBD-F	4-Fluoro-7-nitro-2,1,3-benzoxadiazole
NDMA	Nitrosodimethylamine
NMR	Nuclear magnetic resonance
NPYR	Nitrosopyrrolidine
NSPs	Non-starch polysaccharides
<b>O</b>	
OH-Trp	Four hydroxytryptophan isomers
OP	Oxygen permeability
ORP	Oxidation-reduction potential
OTA	Ochratoxin A
OTC	Over-the-counter
OVA	Ovalbumin
<b>P</b>	
P&T	Purge and trap
PA	Polyamide
PAM	Polyacrylamide
PB	Potassium benzoate
PB + SL	Potassium benzoate plus 2% sodium lactate
PC	Polycarbonate
PC scores	Principal component scores
PCL	Poly- $\epsilon$ -caprolactone

(Continued)

<b>Abbreviation</b>	<b>Full Name</b>
PCR	Polymerase chain reaction
PDA	Potato dextrose agar
PE	Polyethylene
PEG	Polyethylene glycol
PEPH	Pentafluorophenyl hydrazine
PET	Polyethylene terephthalate
PFP	Pulsed flame photometry
PG	Propylene glycol
PHB	Polyhydroxy butyrate
PIMF	Powdered infant milk formula
Pis	Photoinitiators
PKV	Peak viscosity
PL	Phospholipid
PLS	Partial least squares
PLST	Plasticized starch
PM	Postmortem
PMEs	Pectin methylesterases
PP	Polypropylene
PRA	Probabilistic risk assessment
PS	Polystyrene
PS	Potassium sorbate
PSB	Progressive saturation behavior
PSL	Photostimulated luminescence
PUFA/FSA	Polyunsaturated fatty acids/saturated fats
PV	Peroxide value
PVA	Polyvinyl alcohol
PVC	Polyvinyl chloride
PWL	Physiological weight loss
<b>Q</b>	
QRA	Quantitative risk analysis
<b>R</b>	
RDS	Rapidly digestible starch
RF	Radio frequency
ROK	Republic of Korea
RP-HPLC	Reverse-phase high-performance liquid chromatography
RS	Resistant starch
RTE	Ready-to-eat
RT-PCR	Real-time polymerase chain reaction
RVA	Rapid Visco Analyzer
RY	Red skin, yellow flesh
$R_z$	Gyration radius
<b>S</b>	
SA	Sodium alginate
SC	Sodium carbonate
SCF	Scientific Committee on Food
SDE	Steam distillation solvent extraction

---

Abbreviation	Full Name
SDS	Slowly digestible starch
SDS-PAGE	Sodium dodecyl sulfate polyacrylamide gel electrophoresis
SEC	Size exclusion chromatography
SE-HPLC	Size exclusion high-performance liquid chromatography
SEM	Scanning electron microscopy
SFE	Supercritical fluid extraction
SGR	Specific growth rate
SL + SDA	Sodium lactate plus 0.1% sodium diacetate
SPC	Standard plate count
SPI	Soy protein isolate
SPME	Solid-phase microextraction
SRD	Simulated retail display
SS	Sago starch
STPP	Sodium tripolyphosphate
<b>T</b>	
$T_0$	Onset temperature
TAA	Triaxial angular accelerometer
TBA	Thiobarbituric acid
TBARS	Thiobarbituric acid reactive substances
TBC	Total bacterial count
$T_c$	Conclusion temperature
TCA	Trichloroacetic acid
TEG	Triethylene glycol
TGA	Thermogravimetric analysis
TI	Trypsin inhibitor
TIA	Trypsin inhibitor activities
Tinuvin P	2,2-Hydroxy-5- <i>tert</i> -octyl-phenyl benzotriazole
TL	Thermoluminescence
$T_m$	Melting point
TMAH	Tetramethylammonium hydroxide
TMAN	Trimethylamine
$T_p$	Peak temperature
TPL	Total phospholipids
TRP	Tryptophan
TS	Tensile strength
TSP	Total aerobic plate count
TVBN	Total volatile base nitrogen
TVC	Total viable microbial counts
<b>U</b>	
UHMWPE	Ultra-high-molecular-weight polyethylene
UHP	Ultra-high hydrostatic pressure
USDA	U.S. Department of Agriculture
UTS	Ultimate tensile strength
UV	Ultraviolet

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(Continued)

<b>Abbreviation</b>	<b>Full Name</b>
<b>V</b>	
VBN	Volatile basic nitrogen
<b>W</b>	
WAC	Water absorption capacity
WAXS	Wide-angle X-ray scattering
WG	Wheat gluten
WGC	Wet gluten content
WHO	World Health Organization
WP	White skin, purple flesh
WPC	Whey protein concentrate
WPI	Whey protein isolate
WS-chitosan	Water-soluble chitosan
WTP	Willingness to pay
WVP	Water vapor permeability
WVTR	Water vapor transmission rate
<b>X</b>	
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction

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