Standard Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment[1]

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INTRODUCTION

The purpose of this guide is to present information on the use of ionizing energy (radiation) in treating fresh agricultural produce to control insects and other arthropod pests, in order to meet phytosanitary requirements.

This guide is intended to serve as a recommendation to be followed when using irradiation technology where approved by an appropriate regulatory authority. It is not to be construed as a requirement for the use of irradiation nor as a required code of practice. While the use of irradiation involves certain essential requirements to attain the objective of the treatment, some parameters can be varied in optimizing the process.

This guide has been prepared from a Code of Good Irradiation Practice published by the International Consultative Group on Food Irradiation (ICGFI), under the auspices of the Food and Agriculture Organization (FAO), the World Health Organization (WHO), and the International Atomic Energy Agency (IAEA). **(1)**[2]

1. Scope

1.1 This guide provides procedures for the radiation processing of fresh agricultural produce, for example, fruits, vegetables, and cut flowers, as a phytosanitary treatment. This guide is directed primarily toward the treatment needed to control regulated pests commonly associated with fresh agricultural produce.

1.2 The typical absorbed dose range used for phytosanitary treatments is between 150 gray (Gy) and 600 gray (Gy). The practical minimum or maximum dose of a treatment may be higher or lower than this range, depending on the type of pest to be controlled and the radiation tolerance of a particular type of fruit. If the minimum effective dose necessary to achieve the desired phytosanitary effect is greater than the radiation tolerance of the produce, then irradiation is not an appropriate treatment (see 5.2).

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E170 Terminology Relating to Radiation Measurements and Dosimetry

F1640 Guide for Selection and Use of Packaging Materials for Foods to Be Irradiated

2.2 *ISO/ASTM Standards:*

51204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing

51261 Guide for Calibration of Routine Dosimetry Systems for Radiation Processing

51431 Practice for Dosimetry in Electron Beam and X-ray (Bremsstrahlung) Irradiation Facilities for Food Processing

51539 Guide for Use of Radiation-Sensitive Indicators

2.3 *Codex Alimentarius Commission Recommended International Codes of Practice and Standards:*[4]

CX STAN 1-1985, Rev. 1991, Amd 2001 General Standard for the Labeling of Prepackaged Foods

[1] This guide is under the jurisdiction of ASTM Committee E61 on Radiation Processing and is the direct responsibility of Subcommittee E61.05 on Food Irradiation.

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from Joint FAO/WHO Food Standards Programme Joint Office, FAO, Viale delle Terme di Caracalla 00100 Rome, Italy.

CX STAN 106-1983, Rev. 2003 General Standard for Irradiated Food
CAC/RCP 19-1979, Rev. 2003 Recommended International Code of Practice for the Radiation Processing of Food

2.4 *ISO Standards:*[5]

ISO 873 Peaches—Guide to Cold Storage
ISO 931 Green Bananas—Guide to Storage and Transport
ISO 1134 Pears—Guide to Cold Storage
ISO 1212 Apples—Guide to Cold Storage
ISO 1838 Fresh Pineapples—Guide to Storage and Transport
ISO 2168 Table Grapes—Guide to Cold Storage
ISO 2826 Apricots—Guide to Cold Storage
ISO 3631 Citrus Fruits—Guide to Cold Storage
ISO 3659 Fruits and Vegetables—Ripening After Cold Storage
ISO 6660 Mangoes—Guide to Storage
ISO 6661 Fresh Fruits and Vegetables—Arrangement of Parallelpipedic Packages in Land Transport Vehicles
ISO 6664 Bilberries and Blueberries—Guide To Cold Storage
ISO 6665 Strawberries—Guide to Cold Storage
ISO 6949 Fruits and Vegetables—Principles and Techniques of the Controlled Atmosphere Method of Storage
ISO 7558 Guide to the Prepacking of Fruits and Vegetables

3. Terminology

3.1 *Definitions:*

3.1.1 Other terms used in this guide may be defined in Terminology E170.

3.1.2 *absorbed dose*—quantity of ionizing radiation energy imparted per unit mass of a specified material. The SI unit of absorbed dose is the gray (Gy), where one gray is equivalent to the absorption of 1 joule per kilogram of the specified material (1 Gy = 1 J/kg).

3.1.2.1 *Discussion*—A standard definition of absorbed dose appears in Terminology E170.

3.1.3 *dose distribution*—variation in absorbed dose within a process load exposed to ionizing radiation.

3.1.4 *pest*—any species, strain or bio type of plant, animal or pathogenic agent injurious to plant or plant products (**2**).

3.1.5 *process load*—volume of material with a specified product loading configuration irradiated as a single entity.

3.1.6 *quarantine pest*—a pest of potential economic importance to an endangered area and not yet present there, or present but not widely distributed and being officially controlled (**3**).

3.1.7 *quarantine treatment*—pertaining to the killing, removal, or rendering infertile of regulated plant pests on host material that has been placed in quarantine (or seized and detained) by regulatory authorities because of the potential or actual presence of a quarantine pest (**4**).

3.1.8 *regulated non-quarantine pest*—non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party (**3**).

3.1.9 *regulated pest*—quarantine pest or a regulated non-quarantine pest (**3**).

3.1.10 *transport system*—the conveyor or other mechanical means used to move the process load through the irradiator.

4. Significance and Use

4.1 The purpose of radiation treatment, as discussed in this guide, is to minimize the pest risk and to maximize the safety associated with the movement and use of fresh agricultural produce.

4.2 Irradiation as a phytosanitary treatment can prevent development or emergence of the adult stage where adults are not present in the agricultural produce (for example, fruit flies) or sterilize the adult where that stage is present (for example, weevils). (**4**)

5. Selection of Fresh Agricultural Produce for Irradiation

5.1 Most fresh agricultural produce is not adversely affected at the minimum doses indicated in 8.5.2. In particular, the following fruits have been found to be tolerant of those minimum doses: apple, cantaloupe, carambola, cherry, citrus, currant, date, fig, grape, guava, honeydew melon, kiwi, lychee, mango, muskmelon, nectarine, papaya, peach, prune, raspberry, strawberry, and tomato.

5.2 Some fresh agricultural produce may be damaged or exhibit unacceptable changes in shelf-life, color, taste, or other properties at the minimum doses indicated in 8.5.2, making it necessary to evaluate the effects of irradiation on the fruit at the required dose level. Differences among varieties, origins, growing and harvest conditions,, and elapsed time between harvest and processing should be considered.

5.3 Irradiation of product will result in a distribution of absorbed dose in a process load, which is characterized by a maximum and minimum absorbed dose. Thus, in addition to evaluating the suitability of treating product at the minimum dose necessary to inactivate pests, tolerance of the product to the expected maximum dose should be evaluated.

6. Packaging

6.1 Guide F1640 provides guidance on packaging materials in contact with food during irradiation.

6.2 Appropriate packaging materials should be used for safeguarding the produce as part of the effort to ensure phytosanitary integrity (for example, see Ref (**5**)).

7. Pre-Irradiation Product Handling and Treatment

7.1 Fresh agricultural produce intended to be irradiated should be of good overall quality and reflect the results of good agronomic practices.

7.2 Fresh agricultural produce should be appropriately segregated or otherwise safeguarded prior to irradiation as part of the effort to ensure phytosanitary integrity.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

7.3 Normal storage procedures should be used prior to radiation treatment. Pre-irradiation storage should include appropriate temperature and atmospheric conditions. Information on storage conditions is provided in ISO Standards (see 2.4).

7.4 It may not be possible to distinguish irradiated from non-irradiated product by inspection. It is essential that appropriate means integral with facility design, such as physical barriers or clearly defined staging areas, be used to separate non-irradiated product from irradiated product.

NOTE 1—Radiation-sensitive indicators undergo a color change when exposed to radiation in the pertinent dose range. These indicators may be useful within the irradiation facility as a visual check for determining whether or not a product has been exposed to the radiation source. They are not dosimeters intended for measuring absorbed dose and must not be used as a substitute for proper dosimetry. Information about dosimetry systems and the proper use of radiation-sensitive indicators is provided in ISO/ASTM Guides 51261 and 51539, respectively.

8. Irradiation

8.1 *Standard Operating Procedures (SOPs)*—Standard operating procedures for food irradiation are documented procedures for ensuring that the absorbed-dose range and irradiation conditions selected by the radiation processor are adequate under commercial processing conditions to achieve the intended effect on a specific product in a specific facility. These procedures should be established and validated by qualified persons having knowledge in irradiation requirements specific for the food and the irradiation facility (see CAC/RCP 19).

8.2 *Radiation Sources*—The sources of ionizing radiation that may be employed in irradiating fresh agricultural produce are limited to the following (see CX STAN 106):

8.2.1 *Isotopic Sources*—gamma rays from the radionuclides ^{60}Co (1.17 and 1.33 MeV) or ^{137}Cs (0.66 MeV);

8.2.2 *Machine Sources*—X-rays and accelerated electrons.

NOTE 2—The Codex Alimentarius Commission as well as regulations in some countries currently limit the maximum electron energy and nominal X-ray energy for the purpose of food irradiation (CX STAN 106 and Ref (**6**)).

8.3 *Absorbed Dose:*

8.3.1 *Absorbed Doses Required to Accomplish Specific Effects*—Food irradiation specifications provided by the owner of the product should include minimum and maximum absorbed dose limits: a minimum necessary to ensure the intended effect, and a maximum to prevent product degradation. One or both of these limits may be prescribed by regulation for a given application. See, for example, FDA and USDA regulations (**5**, **7**). The irradiation process must be configured to ensure that the absorbed dose achieved is within these limits throughout each process load. Once this capability is established, the absorbed dose values for each production run must be monitored and recorded (see 11.2.2).

8.3.2 *Doses to Control Various Pests*—Appendix X1 lists the many quarantine pests of fresh agricultural produce. The sensitivity of a pest to radiation varies with the life stage of the pest at the time of irradiation (see Note 3). The effect of irradiation at one stage may carry over to, and be more apparent in, a later stage.

NOTE 3—Infestation of a fruit with fruit flies occurs when the adult female lays eggs in the agricultural produce. Later, these eggs hatch and larvae emerge. These larvae feed and develop in the fruit and in this manner damage it. The larvae leave the fruit upon maturation and undergo pupation in the ground. In packaged agricultural produce, pupation may occur in the container. Seed weevils can infest fresh agricultural produce at an early stage and upon emergence as adults, damage the seed and the fruit. One should concentrate on developing a treatment against the most radiation-tolerant stage, that can be reasonably expected to be in, on, or with the fresh agricultural produce. The most tolerant stage is usually the one closest to the adult if the adult itself is not present in the agricultural produce.

8.4 *Routine Production Dosimetry:*

8.4.1 Routine dosimetry is part of a verification process for establishing that the irradiation process is under control.

8.4.2 Select and calibrate a dosimetry system appropriate to the radiation source being used, the environmental conditions, and the range of absorbed doses required (see ISO/ASTM 51261 and Refs (**8**)and (**9**)).

8.4.3 Verify that the product receives the required absorbed dose by using proper dosimetric measurement procedures, along with appropriate statistical controls, and documentation. Place dosimeters in or on the process load at locations of maximum and minimum absorbed dose. If those locations are not accessible, place dosimeters at reference locations that have a known and quantifiable relationship to the maximum and minimum absorbed dose locations (see ISO/ASTM Practices 51204 and 51431).

8.4.4 The size and shape of the process load are determined partly by certain design parameters of the irradiation facility. Critical parameters include the characteristics of the transport system and of the radiation source as they relate to the dose distribution within the process load. The size and shape of the produce and the minimum and maximum dose limits may also affect the loading configuration of the process load.

8.5 *Criteria for Assessing Irradiation Efficacy:*

8.5.1 The key criterion for acceptance of a phytosanitary treatment is the verification that the absorbed dose is sufficient to achieve the required level of phytosanitary security.

8.5.2 The minimum absorbed dose specified to achieve an acceptable level of phytosanitary security is usually established by regulatory agencies. Efficacy should be established on the basis of scientific studies using statistically significant numbers of the pest.

NOTE 4—In the United States for example, quarantine treatments for tephritid fruit flies have often required 99.9968 % efficacy (also known as probit 9) at the 95 % confidence level. This means approximately 94 000 insects must be treated without any emerging adults.

NOTE 5—A minimum absorbed dose of 400 Gy has been shown to be effective to meet phytosanitary criteria for treatment of fresh agricultural produce for most quarantine pests. Sustained research and experience with the treatment of certain quarantine pests have demonstrated that lower doses may be sufficient (**5**).

NOTE 6—Accepted minimum doses may vary with different national plant protection organizations (NPPOs). Users should always contact such authorities to determine the required minimum effective dose for the type of pest and type of produce to be treated before using irradiation as a phytosanitary treatment.

9. Post-Irradiation Handling and Storage

9.1 Handle and store irradiated fresh agricultural produce in the same manner as non-irradiated fresh agricultural produce.

A safeguard system that provides security against post-irradiation infestation of the products must be used (see Section 7).

10. Labeling

10.1 Many governments have adopted special labeling requirements (see Section 5.2, Codex STAN 1) for irradiated foods because some consumers may wish to choose between irradiated and non-irradiated foods. Labeling may also provide information about the purpose and benefits of the treatment. A number of countries have adopted the internationally recognized "Radura" symbol (see Fig. 1) as a means of labeling. In some countries the symbol must be accompanied by a statement, such as "treated with radiation" or "treated by irradiation."

NOTE 7—This is a requirement in the United States (**6**).

11. Documentation

11.1 Ensure that each lot of product to be processed carries an identification number or other code that will distinguish it from other lots of product in the facility. Use this identification on all lot documents.

NOTE 1—Typically Green in Color.

FIG. 1 Radura Logo

11.2 Establish a record of the operation of the irradiation facility.

11.2.1 Record and document the date the lot arrives at the facility, the date it is irradiated, the starting and ending times of the irradiation, the date the lot leaves the facility, the name of the operator, and any special conditions that could affect the irradiation process or the irradiated product.

11.2.2 Record and document all dosimetry data associated with product absorbed-dose mapping, and routine processing. See ISO/ASTM Practices 51204 and 51431.

11.2.3 Record and document any deviation from the scheduled process that could help assess the validity of the process.

11.3 Audit all documentation prior to product release to ensure that records are accurate and complete. The person making the audit should sign the documentation. Make all deficiencies the subject of a separate file available for examination by a regulatory authority.

11.4 Retain all records about each lot irradiated at the facility for the period of time specified by relevant authorities and have them available for inspection as needed.

11.5 Ensure that documentation accompanying the shipment of irradiated product includes the name of the product owner, the name and address of the irradiation facility, description of the product irradiated including the lot number or other identifier (see 11.1), the irradiation date, and any other information required by the product owner, irradiator, or government authority.

12. Keywords

12.1 agricultural produce; arthropod pest; food; fruit; insect; insect control; irradiation; labeling; packaging; phytosanitary treatment; processing; quarantine

APPENDIX

(Nonmandatory Information)

X1. SOME SPECIES OF QUARANTINE IMPORTANCE (See Table X1.1)

TABLE X1.1 Some Species of Quarantine Importance[A]

Scientific Name	Common Name	Primary Economic Hosts[B]	Geographic Distribution
		Diptera	
Anastrepha fraterculus	South American fruit fly	apple, guava, citrus, peach	Mexico to South America
Anastrepha grandis		cucurbits	South America, Panama
Anastrepha ludens	Mexican fruit fly	citrus, mango, peach	Mexico, Central America
Anastrepha obliqua	West Indian fruit fly	mango, guava, *Spondias*	Caribbean, Mexico to South America
Anastrepha serpentina		citrus, mango, guava	Mexico to South America
Anastrepha striata	Guava fruit fly (New World)	guava	Mexico to South America
Anastrepha suspensa	Caribbean fruit fly	guava, loquat, citrus	Greater Antilles, Florida
Bactrocera carambolae	Carambola fruit fly	many fruits, especially carambola	Malayan Peninsula, Indonesia, Surinam
Bactrocera cucumis		cucurbits, tomato, papaw	Australia
Bactrocera cucurbitae	Melon fly	cucurbits	Africa, Southeast Asia, Pacific Islands
Bactrocera dorsalis	Oriental fruit fly	many fruits	Asia
Bactrocera oleae	Olive fly	olive	Europe, Africa, West Asia
Bactrocera papayae		many fruits, especially mango & papaya	Malayan Peninsula, Indonesia
Bactrocera passiflorae	Fiji fruit fly	many fruits, especially citrus	Fiji
Bactrocera philippinensis		many fruits, especially mango & papaya	Philippines
Bactrocera psidii	Guava fruit fly	guava, mango	Pacific Islands
Bactrocera tryoni	Queensland fruit fly	many fruits	Australia
Bactrocera tsuneonis	Japanese orange fly	citrus	Japan, China
Ceratitis capitata	Mediterranean fruit fly	most fruits	Africa, Asia, America, Europe
Ceratitis punctata		cacao, mango, guava	Africa
Ceratitis rosa	Natal fruit fly	many fruits	Africa
Ceratitis rubivora	Blackberry fruit fly	berries	Africa
Dacus cucumarius		cucurbits	Africa
Liriomyza trifolii	Serpentine leaf miner	many plants, especially composits	Americas, Europe, Africa
Myiopardalis pardalina	Baluchistan melon fly	melons	Southwest Asia
Rhagoletis cerasi	European cherry fruit fly	cherry, honey-suckle, soft fruits	Europe
Rhagoletis cingulata	Eastern (U.S.) cherry fruit fly	cherry	North America
Rhagoletis fausta	Black cherry fruit fly	cherry	North America
Rhagoletis indifferens	Western (U.S.) cherry fruit fly	cherry	North America
Rhagoletis pomonella	Apple maggot	apple	North America
		Lepidoptera	
Cryptophlebia leucotreta	False codling moth	cotton, maize, many fruits, especially citrus	Southern Africa
Cryptophlebia ombrodelta	Macadamia nut borer	macadamia, lychee	Australia
Cydia molesta	Oriental fruit moth	deciduous fruits	Temperate regions
Cydia pomonella	Codling moth	deciduous fruits	Temperate regions
Epiphyas postvittana	Light brown apple moth	deciduous fruits	Australia, Hawaii, New Zealand, United Kingdom
Lobesia botrana	Vine moth	grapes	Europe
Prays citri	Citrus flower moth	citrus	Europe, Asia
		Coleoptera	
Cryptorhynchus mangiferae	Mango seed weevil	mango	Asia, Africa, Australia, West Indies
Heilipus lauri	Avocado seed weevil	avocado	Mexico, Central America
		Hemiptera-Homoptera	
Aleurocanthus woglumi	Citrus black fly	many fruits, citrus, ornamentals	Tropics and subtropics
Hemiberlesia lataniae	Latania scale	various fruits, avocado in particular	North and South America, Asia, Europe, Africa
Leptoglossus chilensis		various deciduous fruits	Chile
Quadraspidiotus perniciosus	San Jose scale	many fruits, apple in particular	Americas, Asia, Europe, Africa
Pseudococcus spp.	Mealy bugs	citrus, ornamentals	Various
		Thysanoptera	
Caliothrips fasciatis	Bean thrips	beans	North America, Europe
		Acaridae	
Brevipalpus chilensis		grapes	Chile
Tetranychus mcdanieli	McDaniel mite	deciduous fruits	North America

[A] The original list was developed by the International Consultative Group on Food Irradiation, Task Group Meeting on Irradiation as a Quarantine Treatment, Chiang Mai, Thailand, February 1986, IAEA, Vienna Austria. Additions and changes have been made to this table to follow current nomenclature.
[B] Inclusion of a commodity in this table does not necessarily imply that pests present on this commodity can be controlled by irradiation.

References

(1) International Consultative Group on Food Irradiation (ICGFI), *Code of Good Irradiation Practice for Insect Disinfestation of Fresh Fruits (As a Quarantine Treatment)*, ICGFI Document No. 7, International Atomic Energy Agency, Vienna, Austria, 1991.

(2) ISPM No. 18: *Guidelines for the use of irradiation as a phyosanitary measure*, FAO, Rome, 2003.

(3) ISPM No. 5: *Glossary of phytosanitary terms*, FAO, Rome, 2003.

(4) Hallman, G. J., Irradiation as a Quarantine Treatment, In: Molins, R., Ed., Food Irradiation, John Wiley & Sons, Inc., New York, NY, 2001, pp. 113–130.

(5) United States Code of Federal Regulations, Title 7, Section 305.31, 7 CFR 305.31, January 2006.

(6) United States Code of Federal Regulations, Title 21, Section 179.26, 21 CFR 179.26, April 2004.

(7) United States Code of Federal Regulations, Title 21, Section 179.25, 21 CFR 179.25, April 2004.

(8) McLaughlin, W. L., Boyd, A. W., Chadwick, K. H., McDonald, J. C., and Miller, A., *Dosimetry for Radiation Processing*, Taylor and Francis, London, New York, Philadelphia, 1989.

(9) *Dosimetry for Food Irradiation*, Technical Reports Series No. 409, International Atomic Energy Agency, Vienna 2002.