*CRP D62008*
*Meeting RC-1143.4*

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# *The Development of Generic Irradiation Doses for Quarantine Treatments*

## *REPORT OF THE 4TH RESEARCH COORDINATION MEETING*

***IAEA Headquarter, Vienna, Austria, 2 – 6 June 2014***

FAO / IAEA Division of Nuclear Techniques in Food and Agriculture

Vienna, Austria, 2014

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# 1. Introduction

The fourth and final Research Coordination Meeting (RCM) of the Coordinated Research Project (CRP) on the Development of Generic Irradiation Doses for Quarantine Treatments was held in the headquarters of IAEA in Vienna, Austria from 2 to 6 June 2014.

This CRP has advanced work to establish validated irradiation treatments to control quarantine pests and considerable progress has been made since the project commenced in 2009. The results of this research will strengthen existing irradiation standards developed under the International Plant Protection Convention (IPPC), thereby helping to enable international trade for various fruits and vegetables through the use of generic irradiation doses for a wide range of quarantine pests.

# 2. Objectives

The overall objective of the CRP was to validate generic treatment doses for groups of arthropod pests of quarantine significance in international trade. Secondary objectives included an examination of the effects of low oxygen commodity storage and dose rate on the efficacy of treatments against insect pests and the tolerance of food commodities to the treatment doses.

Research assisted the development of generic dose treatments against taxonomic groups of quarantine pests of the phylum Arthropoda as well as directly establish minimum doses that will provide quarantine security against specific insect pests.

Research on specific non-fruit fly (Tephritidae) pest species or groups was conducted at different locations by researchers using practices that were adequate for phytosanitary applications of irradiation, such as accurate, traceable dosimetry, acceptable pest-rearing methods and precise determinations of efficacy. Efficacy under commercial conditions of oxygen stress, whether intentional or passive, was also tested for certain applications. Tolerances of specific commodities to irradiation treatment under various commercial conditions were also studied.

# 3. Background

Regulatory authorities and scientists from many internationally recognised institutions have generated research data on the effectiveness of irradiation as a quarantine treatment against specific insect pests that can infest various commodities such as fruits and vegetables. These authorities have concluded that the development of generic irradiation dose treatments suitable to control a broad range of pests is both feasible and desirable and in many cases generic dose treatments could negate the need to develop or validate specific irradiation dose treatments tailored to individual arthropod species.

The application of ionizing radiation (gamma, electron beam or X ray irradiation) as a phytosanitary treatment has expanded rapidly in recent years with several countries irradiating fruit in order to meet quarantine requirements for exports. This application of irradiation technology is important for both developed and developing countries due to uncertainties on the future availability and increasing price of methyl bromide, a fumigant facing increasing restrictions under the Montreal Protocol, but still widely used as a phytosanitary and pre-shipment treatment for pests of quarantine significance. There is a need for validated alternative post-harvest phytosanitary methods, and ionizing radiation is a viable and effective alternative as demonstrated by applied research leading to the development of additional irradiation treatments.

Since 1981, the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture has supported research, education and cooperation in the use of ionising radiation as a phytosanitary treatment. In this regard, the Food and Environmental Protection Sub-programme has implemented four coordinated research projects in the area of phytosanitary irradiation (PI). These projects established the basis for developing national and international standards on the use of irradiation as a phytosanitary treatment. Specifically, in

2003 the International Plant Protection Convention (IPPC) approved the International Standard for Phytosanitary Measure (ISPM), Guidelines for the Use of Irradiation as a Phytosanitary Measure (ISPM 18), and subsequently established irradiation treatments under the IPPC Standard on Phytosanitary Treatments for Regulated Pests (ISPM 28).

In 2009, eight PI treatments were adopted, a year later a further three treatments were included, and an additional three treatments were adopted at the March 2011 meeting of the Commission on Phytosanitary Measures (CPM) of the International Plant Protection Convention (IPPC), making a total of fourteen internationally adopted PI treatments. All fourteen treatments are included in the annexes to the standard ISPM No. 28 Phytosanitary Treatments for Regulated Pests.

Table 1: List of annexes to the standard ISPM No. 28

| Document | Adoption date and Title | Publication |
|---|---|---|
| Annex 01 | PT 1 (2009): Irradiation treatment for *Anastrepha ludens* | 2011-12-15 |
| Annex 02 | PT 2 (2009): Irradiation treatment for *Anastrepha obliqua* | 2011-12-15 |
| Annex 03 | PT 3 (2009): Irradiation treatment for *Anastrepha serpentin*a | 2011-12-15 |
| Annex 04 | PT 4 (2009): Irradiation treatment for *Bactrocera jarvisi* | 2011-12-15 |
| Annex 05 | PT 5 (2009): Irradiation treatment for *Bactrocera tryoni* | 2011-12-15 |
| Annex 06 | PT 6 (2009): Irradiation treatment for *Cydia pomonella* | 2011-12-15 |
| Annex 07 | PT 7 (2009): Irradiation treatment for fruit flies of the family Tephritidae (generic) | 2011-12-15 |
| Annex 08 | PT 8 (2009): Irradiation treatment for *Rhagoletis pomonella* | 2011-12-15 |
| Annex 09 | PT 9 (2010): Irradiation treatment for *Conotrachelus nenuphar* | 2011-12-15 |
| Annex 10 | PT 10 (2010): Irradiation treatment for *Grapholita molesta* | 2011-12-15 |
| Annex 11 | PT 11 (2010): Irradiation treatment for *Grapholita molesta* under hypoxia | 2011-12-15 |
| Annex 12 | PT 12 (2011): Irradiation treatment for *Cylas formicarius elegantulus* | 2012-07-17 |
| Annex 13 | PT 13 (2011): Irradiation treatment for *Euscepes postfasciatus* | 2012-07-17 |
| Annex 14 | PT 14 (2011): Irradiation treatment for *Ceratitis capitata* | 2012-07-17 |

As was indicated at the third research coordination meeting of this CRP, four phytosanitary treatments were proposed for consideration as international standards (two generic and two specific to insect species); The two generic dose treatments for phytosanitary treatments against early life-stages of Lepidoptera were prepared for consideration as IPPC standards[1] on the basis of previously published research and research from CRP participants, however more work is necessary using large numbers of Lepidoptera and these have not be approved as standards by the IPPC. The two irradiation treatments specific to certain species are currently being considered by the IPPC and it is envisaged that they will be included as standard phytosanitary treatments for regulated pests:

- Irradiation for *Ostrinia nubilalis* at 289 Gy (2012-009)
- Irradiation for *Dysmincoccus neobrevipes* Beardsley, *Planococcus lilacinus* (Cockerell), and *Planococcus minor* (Maskell) (Hemiptera: Pseudococcidae) at 231 Gy (2012-011).

[1] The case for a generic phytosanitary irradiation dose of 250 Gy for Lepidoptera eggs and larvae. Radiation Physics and Chemistry, Volume 89, August 2013, Pages 70–75 and The case for a generic phytosanitary irradiation dose of 400 Gy for Lepidoptera that infest shipped commodities as pupae. Journal of Economic Entomology 2013 v.106 no.2

Despite these successes, important gaps in knowledge remain. Prior to this CRP limited research had been performed on the susceptibility to irradiation of other critical (non-fruit fly) insect pests of quarantine significance. Such pests include mites, thrips, mealybugs, weevils, leaf miners, aphids and scale insects.

A Consultants Meeting held at the IAEA Headquarters from 3 - 7 November 2008 considered these gaps in knowledge. The purpose of the Consultants Meeting was to advise the Food and Environmental Protection and the Insect Pest Control sub programmes of the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture (NAFA) on the proposed Coordinated Research Project (CRP) on the Development of Generic Irradiation Doses for Quarantine Treatments. The Meeting recommended that:

i. A set of guidelines should be developed during the first RCM on the application and reporting of dosimetry to ensure consistency.

ii. Research protocols should be developed during the first RCM that include, among other things, definitions of the measure of efficacy for irradiation as a phytosanitary option, for all the arthropod groups that will be studied under the CRP.

iii. The CRP outcomes should facilitate the finalisation of IPPC treatments and standards that deal with phytosanitary applications of irradiation.

iv. A high priority should be given to develop a generic dose for all phytophagous mites.

v. A generic dose for all weevils should also be developed.

vi. Reducing the generic dose of 400 Gy for all Insecta (except pupae and adults of Lepidoptera) should be investigated.

vii. The CRP framework should consider the outputs of previous CRP and synergies with related TC country and regional irradiation projects.

viii. Large scale testing up to 30 000 insects should be considered in confirming that the selected dose is efficacious.

The first Research Coordination Meeting, held in Vienna, Austria from 5 to 9 October 2009 noted that three of the recommendations could not be fully addressed, namely:

- Recommendation (iv): Although the research will start to establish a body of work that could eventually result in a generic dose for the quarantine treatment of all mites, the CRP includes work on four species of phytophagous mites, and it is unlikely that a generic dose could be agreed based on four species.
- Recommendation (v) cannot be addressed as none of the CRP participants are studying weevils.

Recommendation (vi): In making this recommendation, it was assumed that the 400 Gy generic dose for all Insecta (excluding pupae and adults of Lepidoptera) would be accepted by the IPPC.

The second Research Coordination Meeting (RCM) of the Research Coordination Project met at the National Center for Electron Beam Research, Texas A&M University, College Station, Texas USA from 11 to 15 April 2011. The meeting reviewed the results and proposed research of individual participants, evaluated the extent to which generic doses for specified groups of arthropods could be established and discussed research to fill any gaps in the data need for setting generic doses.

The meeting recalled that one of the considerations that differentiate irradiation from other phytosanitary treatments is the fact that quarantine irradiation treatments may not lead to acute mortality. Phytosanitary security can be assured by the prevention of further development and/or reproduction of pests and, following irradiation treatment it is possible that quarantine inspectors could find live (though non-viable) insects in properly irradiated commodities. As a result, there is no independent confirmation of efficacy, such as the presence of dead insects treated by other phytosanitary methods. Therefore, the efficacy of irradiation treatments must be assured through appropriate research to confirm the process. Precise definitions of post-irradiation responses are therefore required for the benefit of government inspectors and commercial users.

The conclusions and recommendations of the Second RCM were as follows:

**Conclusions:**

i. The presentations demonstrated considerable progress in achieving the objectives of the CRP and some specific generic treatment doses should be proposed by the end of the project.
ii. It was noted that the dosimetry carried out by the different researchers appeared to be highly consistent: the measured doses closely correlated with target doses within the tolerance of the dosimetry dose comparison system.
iii. The meeting recognized the usefulness of an on-line Internet forum, with appropriate resources, which will enable participants to readily communicate effectively on issues of mutual concern.
iv. Working Groups were established to address specific issues and improve collaboration and achieve synergies on common research topics.
v. The presence of observers to the meeting substantially enriched the discussions.

**Recommendations:**

i. The on-line discussion forum was recognized as being a very valuable resource and programing support should be continued.
ii. The meeting recommended continued liaison and cooperation with both the IPPC secretariat and the TPPT in order to facilitate the adoption of generic irradiation treatments stemming from this Project.
iii. The meeting continued to encourage further funding and implementation of training courses related to the application of international standards, the operation of irradiation facilities and quarantine inspection and regulatory control by international organizations as per RAS5050. The group thought that there was a particular need for training of NPPO inspectors with regard to the inspection of irradiated consignments.
iv. In order to increase the number of species tested within the selected insect groups, participants were encouraged to generate dose-response data for any additional species which are readily available. These doses-responses curves should be compared, and confirmatory testing carried out, on only the most radio-tolerant species.
v. Participants who were unable to attend should use the On-line forum to update the CRP on their progress, and any other concerns.
vi. Future meetings should be arranged to take best advantage of local observers who can contribute to the discussions.

The third Research Coordination Meeting (RCM) of the Research Coordination Project (CRP) on the Development of Generic Irradiation Doses for Quarantine Treatments met in Buenos Aires, Argentina from 15 to 19 October 2012.

The meeting reviewed the research results and suggested to give the priority to research on mites, scales, thrips, weevils (*Premnotrypes spp.)* and whiteflies (*Bemisia tabaci*). The results suggested that 250 Gy (and not 400 Gy as was previously estimated by researchers in the area) might be sufficient for the majority of insect pests and the CRP may also result in the development of future generic quarantine treatment doses; e.g. for weevils (170 Gy?) and mites (350 Gy?). Dosimetry issues were discussed and it was emphasised that actual measured doses of irradiation as received by the irradiated samples and the dose distribution / dose uniformity ratio should be reported.
The conclusions and recommendations of the third RCM were as follows:

**Conclusions**

i. The presentations demonstrated excellent progress in achieving the objectives of the CRP; Studies have used considerable numbers of insects in confirmatory tests and several treatments are almost finalized. CRP participants were responsible for all four treatments (including two generic treatments) submitted to the IPPC in response to the 2012 call for irradiation treatments for consideration as annexes to ISPM28. Other treatment doses will be proposed by the end of the project. It is worth noting that the two generic treatment proposals relied heavily on SIT

expertise and data demonstrating the importance of interactions between sections of the Joint FAO/IAEA Division.

ii. Recognizing the importance of dosimetry practices and dosimetry systems, participants have implemented procedures to record doses and have presented these data during the RCM although some have difficulties in obtaining appropriate data from their irradiation treatment provider.

iii. Participants have been collaborating and exchanging information using email and an on-line Internet forum. However, more proposals could have been produced for the IPPC with improved communication. Also, links could be improved with national counterparts at the National Plant Protection Organization (NPPO).

iv. The presence of observers at the meeting enriched the discussions, and encouraged further discussions.

**Recommendations**

i. The CRP is developing both generic dose treatments and species-specific dose treatments. Participants are encouraged to submit phytosanitary treatments that are species specific especially in those cases where the specific treatment dose will be lower than the generic (the majority of cases). A lower dose may be more cost effective and help maintain product quality in cases where product is sensitive to radiation treatment.

ii. Participants should continue to use the dosimetry reporting guidelines agreed at the first RCM and contained in the Research Protocol (Annex C of the first RCM meeting report).

iii. Participants need to keep in touch. First draft manuscripts are needed at the next RCM which should be held in early 2014 at the earliest. Email should be used to keep in touch, announce important activities, exchange information, review and discuss and help each other. For example participants working on the same group of insects should share lists of references, results and conclusions.

iv. Participants should establish a mutually beneficial relationship with their NPPO. This will help participants understand phytosanitary issues in their country and region. It will also help the NPPO understand the expertise participants can provide and solutions for solving these issues. For example contact your NPPO and tell them about this meeting.

v. Observers should be encouraged to attend meeting, for example this is an effective way of ensuring continued liaison and cooperation with both the IPPC secretariat and the TPPT in order to facilitate the adoption of generic irradiation dose treatments stemming from this CRP.

## 4. Fourth Research Coordination Meeting

The fourth RCM was held at IAEA headquarters, Vienna, Austria. Opening remarks were presented on behalf of the FAO and IAEA by Carl Blackburn of the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture. The participants (Annex A) introduced themselves and reviewed the meeting arrangements. The Meeting was chaired by Guy Hallman with Ray Cannon as rapporteur. The list of participants (Annex A) and adopted Agenda (Annex B) are attached.

During his introductory remarks, Carl Blackburn reminded the participants that the overall objective of the project was to validate treatment doses for groups of arthropods of quarantine significance in international trade but that the work had also generated specific treatments for certain species and food stuffs. The particular objectives of this fourth and final RCM were to follow on from the three previous coordination meetings and to review, appraise and summarize research activities and outputs produced over the whole duration of the project. He also expected that arrangements would be made for the publication of the results in a peer-reviewed journal. The logical framework used in formulating the CRP was to be used as the basis

for its evaluation, which included an examination of what had been achieved by each participating organisation and how this has contributed to the objectives of the project as a whole.

## *4.1 Introductory Presentations*

### 4.1.1 Update on the commercial use of irradiation as a phytosanitary treatment

Mr Yves HENON - Food and Environmental Protection, Joint FAO/IAEA Division

Mr Henon summarised the current situation and provided an overview of the commercial application of PI. In 2013, nearly 20,000 tons of fresh produce were irradiated for phytosanitary purpose, mostly by gamma radiation (Table 2).

Table 2: Recent commercial use of Irradiation as a Phytosanitary Treatment.

| Country of Origin | Destination Country | Commodities | Year trade started | Tonnes (2013) | Radiation used | Minimum Dose (Gy) |
|---|---|---|---|---|---|---|
| **Australia** | New Zealand | Mango, papaya, tomato, lychee, capsicum | 2004 | 1,300 | Gamma | **400** |
| **Australia** | Malaysia | Mango | 2011 | 288 | Gamma | **400** |
| **Australia / Queensland** | Australia / other states | Mango | 2012 | 27 | Gamma | **400** |
| **India** | USA | Mango | 2007 | 283 | Gamma | **400** |
| **Mexico** | USA | Guava, manzano pepper, sweet lime, mango | 2008 | 9,526 | Gamma | **150 or 400** |
| **Pakistan** | USA | Mango | 2010 | 5.8 (2012) | X ray * | **400** |
| **South Africa** | USA | Grape | 2013 | 16 | Gamma | **400** |
| **Thailand** | USA | Mangosteen, longan, rambutan | 2007 | 1,060 | Gamma | **400** |
| **USA / Hawaii, Florida** | USA / mainland | Sweet potato, rambutan, longan, curry leaf, papaya, mangosteen | 1995 | 4,300 (2012) | X ray, Gamma | **400 or 165** |
| **Vietnam** | USA | Dragon fruit, rambutan; | 2008 | 1,967 | Gamma+E-Beam | **400** |

** Irradiated on arrival in the USA, all others are irradiated at country of origin*

From 1995 up until 2004 the commercial application of irradiation was only widely used in Hawaii and Florida for inter-state trade, in order to ship fresh produce from Hawaii to other locations within the USA. Although irradiation is still used as a treatment for fresh produce from Hawaii, international trade between nations began with Australia, which was the first country to use PI for this purpose, exporting irradiated mango to New Zealand beginning in late 2004. In subsequent years facilities in other countries began to irradiate ffresh produce for international trade and by 2012 Mexico became the largest exporter of irradiated fruit. Phytosanitary irradiation is now taking place at fifteen facilities in seven countries; five dedicated irradiation facilities (underlined in table 3) and 10 multipurpose irradiation facilities. Two gamma facilities

of a new design recently started operation in Hawaii and Mississippi. From Queensland, Australia now ships mangoes to other states within Australia, to New Zealand and to Malaysia. In 2012, New Zealand also received irradiated tomatoes and capsicum from Australia.

Table 3. Commercial Facilities Irradiating Fresh Produce for Phytosanitary Purposes

| Country | Gamma | EB | X ray |
|---|---|---|---|
| Australia | Steritech (Queensland) | - | - |
| India | Krushak | - | - |
| Mexico | Sterigenics<br>Benebion | - | - |
| South Africa | Hepro | - | - |
| Thailand | TINT-Thai Irradiation Centre<br>Synergy Health | - | - |
| USA | Gateway (MI)<br>Pa'ina (HI)<br>Sterigenics (FL) | Sadex (Iowa)<br>National Research Centre for Electron Beam (Texas) | Hawaii Pride |
| Vietnam | AnPhu | SonSon | - |

A large electron beam facility is under construction in China, it is being built to treatfruit imported from Vietnam at the port of entry in the Guanxi province in Southern China. Several machine sources manufacturers are considering new approaches to food irradiation such as the use of compact self-shielded units that could be easily fitted in a packing-house.

The concept of generic doses, the publication of ISPM 18 and ISPM 28 as well as the proactive attitude of USDA-APHIS have greatly helped these developments. It is expected that the number of bilateral agreements will further increase in the future.

### 4.1.2 Update on Technical Panel on Phytosanitary Treatments and on a proposed CRP on the detection of irradiated insects

Mr Andrew PARKER – Insect Pest Control Laboratory, Joint FAO/IAEA Agriculture and Biotechnology Laboratories

In the past two years five phytosanitary irradiation treatments have been on the work programme of the TPPT. These include three generic treatments (all insects except pupae and adults of Lepidoptera (400 Gy), eggs and larvae of Lepidoptera (250Gy) and pupae of Lepidoptera (350Gy)) and two individual treatments (*Ostrinia nubilalis* (289Gy) and three pseudococcids (231Gy)).

All three of the generic dose proposals were rejected by TPPT on the grounds that there was insufficient data to support the efficacy for all of the taxa included, and they have been removed from the TPPT work programme. It was, however, commented that sufficient data may exist to support a generic dose proposal at the family level for the Tortricidae. The *Ostrinia nubilalis* proposal has been returned to the proposing country for further information, which has been received and the proposal will be submitted to the Standards Committee shortly to go for Member Country comment.

The Pseudococcidae proposal (for *Dysmicoccus neobrevipes*, *Planococcus lilacinus* and *Planococcus minor*) has been submitted for Member Country comments and the comments received. No significant objections were received and the comments have all been addressed. The proposal will be reviewed at the next TPPT meeting and is ready to be submitted to the Standards Committee for Country comment.

The TPPT is also preparing a position paper on the issues connected with the presence of live adults in irradiated commodities, in particular in relation to determining if they have been irradiated and the risk of them dispersing and triggering a regulatory response. A revision of ISPM 18 has also been proposed.

A Consultants' Group Meeting was held in the IAEA in May 2014 to advise on the current status of research and technology for the detection of irradiated insects, in view of the objections sometimes raised by countries to the possibility of live, mobile insects being present in commodities that have undergone phytosanitary irradiation. There is also the possibility of using such techniques to confirm the irradiation status of an unmarked insect caught in a monitoring trap during a pre-harvest sterile insect technique (SIT) programme. This information is being considered as the possible basis for a future CRP.

Current techniques used in the detection of irradiated food were discussed and their applicability to confirming the irradiation status of insects. The techniques can be divided into three groups: chemical detection of radiolytic products; free-radicle detection; and biochemical/microbiological techniques.

Current technology lacks the necessary sensitivity to be used on individual insects but can be used to confirm irradiation of the commodity when the insect is still associated with the commodity. Recent advances in analytical and biochemical techniques could provide substantial gains in sensitivity, potentially getting to the levels needed to analyze individual insects, but research is needed to validate these new techniques and to develop practical test that can be used in the field. Issues of specificity also need to be addressed, if a systems approach is not ultimately acceptable.

### 4.1.3 Status of Generic Phytosanitary Irradiation Treatments

Mr Guy HALLMAN - USDA-ARS, Manhattan, KS, USA

Generic PI treatments are currently used to trade some fresh fruits and vegetables internationally. Three countries (Malaysia, New Zealand, and the United States of America) import these commodities.

Three broad generic treatment proposals were recently not accepted by the International Plant Protection Convention (IPPC) because it was decided that insufficient research supported them. Other generic PI doses should be proposed with this fact in mind.

Research conducted by this CRP during the last 5 years may be sufficient to support other generic PI doses. It is recommended that researchers of this CRP that worked on insects within certain groups for which sufficient data may have been generated get together to write justifications for generic doses for those groups that will be published as peer-reviewed papers in the special issue of *Florida Entomologist* dedicated to this CRP. These groups may be mealybugs and larvae and eggs from the Family Tortricidae (Lepidoptera), for example.

Also, it is recommended that all researchers in this CRP collaborate in a published review of the status of a generic dose for all insects except perhaps pupa and adult Lepidoptera, which are significantly more radio tolerant that the rest of the insects. It probably would be expected that this broad generic dose would not be acceptable to the IPPC without considerable additional research, and, therefore, it probably should not be proposed yet. However, the review would provide a needed status review of the literature and highlight where more data are needed.

## *4.2 Participants reports*

### 4.2.1 Evaluation and Characterization of Alanine/ Electron Paramagnetic Resonance (EPR) Dosimetry System for Low Energy X ray Irradiation (Technical Contract 17053)

Ms Helen KOURY, Brazil - Presented by Mr Kishor MEHTA

The objective was to establish an alanine-EPR dosimetry system, as none is currently available. A good dosimetry system is essential for phytosanitary applications of food irradiation in order to have confidence in the doses at the time that they are established and for routine control, as well as to comply with regulations. ISO/ASTM have published several dosimetry standards e.g. for commercial gamma facilities and research [51900].

The main scope of ISO/ASTM 51900 is to detail the minimum requirements for dosimetry needed to conduct research in order to describe the experimental method for routine experiments, to ensure that the research is useful and understandable and that the overall level of uncertainty and variation in the absorbed dose is documented.

Two types of alanine-EPR dosimeters were used (both small pellets).

- 93% alanine plus binder
- 90% alanine plus binder

This system is offered as service to determine dose values for project participants.

### 4.2.2 Gamma Radiation Quarantine Treatments for Different Groups of Arthropods

Ms Celina HORAK and Mr Guido VAN NIEUWENHOVE - Argentina (Research Contract 15641)

The main objective of the research was to validate the minimum irradiation dose necessary to secure quarantine in the following species: *Trialeurodes vaporariorum (*Hemiptera: Aleyrodidae), *Spodoptera frugiperda* (Lepidoptera: Noctuidae), *Hemiberlesia lataniae* (Hemiptera: Diaspididae) and *Lobesia botrana* (Lepidoptera: Tortricidae). These pest species represent groups for which generic doses are sought worldwide.
Susceptibility tests were used to determine the most tolerant developmental stage(s) in each species. The minimum dose to achieve quarantine control efficacy of 99.99% at the 95% CL were determined. Large-scale tests were carried out to confirm the efficacy dose.

The adult form of *H. lataniae* was found to be the most radiotolerant stage, because adults produced greater numbers of offspring after irradiation than the other stages. A large-scale test was conducted at 200 Gy on 31,877 adults and efficacy as measured by non-hatching of F1 eggs was confirmed at the 99.99% level (95% CL).

*T. vaporariorum*: The pupa was determined to be the most radiotolerant stage found on commodities, as the adult stage is not present. The minimum effective irradiation dose necessary to secure quarantine security at 99.99% (95% CL) non-emergence of normal adults from pupae was 101 Gy.

A large-scale test will be conducted to confirm efficacy of the dose at 99.99%, (95 % CL).

*S. frugiperda*: The sixth-instar larva was confirmed as the most radiotolerant stage, as pupae and adults are not found on shipped commodities.

The minimum dose required to achieve 99.99% (95% CL) prevention of normal adult emergence was 85 Gy based on treatments of 568 sixth-instars larval *S. frugiperda* reared on artificial diet. A large-scale test has to be conducted on sixth-instar larvae, irradiated with the determined dose to achieve 99.99% of efficacy at the 95% CL.

The susceptibility test of irradiated sixth-instar larvae reared on artificial diet vs. a natural host (corn leaves) was done at the sub-efficacious target dose of 60 Gy to have survivors for a comparison. Rearing on corn leaves resulted in a higher number of normal-looking adults; however, the absorbed dose range measured irradiating larvae reared in diet (67-90 Gy) was higher than that for corn-reared (63-68 Gy), suggesting that in the configuration used diet-reared larvae received a higher dose.

Evaluation of different dose-rate effects (almost 100 times different) on sixth-instar larvae, irradiated with 60 Gy showed a higher percentage of normal-looking adults when irradiated with the lower dose rate. However, as before, the dose ranges between the two treatments were markedly different with the higher dose rate receiving a higher total dose.

*L. botrana*: the laboratory rearing conditions were established once approval was obtained from the Argentine NPPO. The staff was trained in the *Lobesia* rearing laboratory in Mendoza province. The tests that

will determine the minimum dose to achieve efficacy on late pupae are going to be conducted. A large-scale test will be done to achieve 99.99% efficacy at the 95% CL. The efficacy measure, possibly non-viability of eggs, will be defined when the results from the minimum dose determination are obtained.

### 4.2.3 Effect of low dose irradiation on the nutritional and postharvest fruit quality of a range of fruit and vegetables

Mr Peter LEACH - Australia (Agreement Holder 15708)

The nutritional and postharvest quality of 'Rival' apricot, 'Stella' cherry, 'Artic Snow' nectarine, 'Elegant Lady' peach, 'Black Amber' plum, 'Red Delicious' apple, 'Galaxy' honeydew melon, peach, 'Triumph' rockmelon, 'Albion' strawberry, 'Flame Seedless' table grape and 'Black Jack' zucchini were investigated using treatments of 150, 400, 600 and 1000 Gy. 1000 Gy was chosen as the highest dose in this study as it is the highest dose permitted for phytosanitary purposes in many countries. Additionally it is close to the range of doses that may be expected in commercial facilities that have a DUR greater than 2.

Radio-tolerance of these fresh fruits, which included the nutritional profile and postharvest fruit quality of each commodity were assessed immediately after irradiation and after removal from recommended periods of cold storage. At doses at and below 1 kGy applied in apricot, cherry, nectarine, peach and plum, the changes in carbohydrate nutrient and functional characteristics were not significant. Postharvest fruit quality was not negatively impacted.

The nutritional and fruit quality parameters assessed were impacted to a greater extent by storage time than by irradiation. Overall, changes to the chemical composition of these fruits are minimal. Macronutrients, including carbohydrates, fats and proteins were not affected. Vitamin losses are minimal at doses below 1 kGy.

Postharvest fruit quality showed little change and many are the same changes that occur with aging and storage. The losses are generally within variations found between varieties of a specific commodity or the losses caused by storage and other preharvest or postharvest conditions. Applications of up to 1 kGy irradiation did not result in any detrimental damage, except in artic snow nectarine and galaxy honey dew melon. At doses ≥ 600 Gy there was increased skin browning and pitting with increasing dose being observed only at the end of the recommended storage period.

All treatments were undertaken at the Australian Nuclear Sciences and Technology Organisation using a research scale gamma irradiator. The overall uncertainty associated with individual dosimeter readings includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2% for Fricke. The dose rate was approximately 9.7 Gy per minute.

Details are available at www.foodstandards.gov.au/code/applications/Pages/A1092-Irradiation.aspx

### 4.2.4 Use of Gamma Radiation to Control Insects and Mites

Mr Valter ARTHUR - Brazil (Research Contract 15201)

Mites (*Brevipalpus phoenicis*) were treated with gamma radiation from Cobalt-60 in air and in high oxygen atmosphere at 100, 200 and 300 Gy at a dose rate of 0.51 kGy/hour. Results show that the sterilizing dose is 300 Gy in both conditions of atmosphere but the effects of gamma radiation increased when mites were irradiated in oxygen.

The leaves of litchi trees infested with mites (*Aceria litchi*) were collected and taken to the laboratory. After a count of the mites, the leaves were placed in plastic bags and irradiated in a Gammacell-220 with a Cobalt-60 source at a dose rate of 0.289 kGy/hr initially at a dose of 200, 400, 600, 800, 1 200, 1 400, 1 600, 1 800 and 2 000 Gy. For each treatment there were approximately 30,000 ± 3,000 mites divided in 3 replicates of 10,000 ± 1,000. Each leaf had approximately 150±15 mites so 70 leaves by repetition for a total of 10,000 ± 1,000 mites per repetition. Immediately after irradiation and during the following 48 hours, the number of

live and dead mites was estimated. The results show that for mites on their natural host the lethal dose 3 days after irradiation is 0.8 kGy.

The effects of gamma radiation on the stages of the life cycle of mites was evaluated. Female mites of *Tetranychus urticae, Tetranychus desertorum, Oligonychus ilicis* were irradiated in a Gammacell-220 with a Cobalt-60 source at a dose rate of 0.486 kGy/hour at doses of 100, 200, 300 and 400 Gy. The results showed that the decrease in eggs and nymphs viability of the mites is directly proportional to the dose. A dose of 200 Gy sterilizes all life cycle stages of *O. ilicis* and a dose of 200 Gy sterilizes all life cycle stages of *T. urticae* and *T. desertorum.*

Harwell dosimeters of the Gammachromic YR$^{@}$ type for the 0.1 – 3.0 kGy range were used for all experiments.

### 4.2.5 Irradiation as Quarantine Treatment of Orange against Citrus Mites

Ms Qunfang WENG – China (Research Contract 15630)

Weng was not present. Her latest study was on the quality of Shatang Mandarin orange (*Citrus reticulata* Banco cv. Shatang) treated by irradiation for phytosanitary purpose. The effect of irradiation on the following components was studied: total soluble solids, ascorbic acid, titratable acidity, peroxidase, superoxide dismutase.

### 4.2.6 Irradiation as a phytosanitary treatment for peach fruit moth and Jack Beardsley mealybug

Mr Zhan GUOPING – China - (Research Contract 15633)

The dose-response tests to prevent adult emergence were conducted on 3- and 5-days old eggs and various larval stages of *Carposina sasakii*. The results showed that tolerance to radiation increased with age and developmental stage. The fifth instar larva (the most advanced stage within the fruits) was determined to be the most radiotolerant stage, requiring an estimated minimum absorbed dose of 209 Gy (95% CI: 195.0, 226.5 Gy) to prevent adult emergence at 99.9968% efficacy (95% confidence level). To compare the effects of various radiation types, the late fifth instar larvae were treated *in vitro* with i) gamma radiation from Cobalt-60, ii）5 MeV X ray and iii）6 MeV X ray. The Abbott's corrected mortality (non-emergence of adult) did not show any significant difference related to dose, type of radiation, progeny or generation. The estimated minimum absorbed doses necessary to prevent adult emergence were quite close in all the treatments (range of mean value: ED99 152.4~159.2 Gy; ED99.9968 195.2~208.7 Gy).

In the confirmatory tests, gamma radiation was applied to 30,850 late fifth instars in apple fruits with a target dose of 200 Gy (171.6-227.8 Gy measured); as a result, only 4 deformed adults emerged (out of 30,850) and these died two days afterwards without depositing any eggs. A dose of 228 Gy can therefore be recommended as a phytosanitary irradiation treatment under ambient atmosphere for the control of peach fruit moth on all commodities with an efficacy of 99.9902% at 95% confidence level. In addition, 3-, 6- and 9-day old pupae were gamma irradiated to observe adult emergence, oviposition and egg hatch. The tolerance to radiation increased with developmental time. A minimum dose of 317 Gy was found to prevent egg hatch on 99.9968% at 95% confidence level.

All stages of nymphs, newly developed females and late stage females (lifespan greater than 5 days) of *Pseudococcus jackbeardsleyi* were gamma irradiated in order to prevent development and reproduction. The results showed that the tolerance to radiation increased with age and developmental stage. The most radiotolerant stage was the late stage females (which contained ovisacs), requiring an estimated 134 to 161 Gy to prevent the emergence of F1 generation 2nd instar nymphs. In the confirmatory tests, a target dose of 150 Gy (133.5-166.0 Gy measured) was applied to i) an estimated 118,520 late stage females reared on potatoes and ii) 49,290 late stage female reared on pumpkins. There was no emergence of F1 generation 2nd

instars. A minimum dose of 166 Gy can therefore, be recommended for phytosanitary treatment of the Jack Beardsley mealybug in contaminated fruits.

A quality test on rambutan 'Rongrien' fruit tissue was conducted 5, 10, and 15 days after irradiation treatment at doses of 300, 600, 900, and 1,200 Gy. Irradiation had no significant effect on ascorbic acid, total acidity, total soluble solids and soluble protein. It was noted that the nutritional quality decreased significantly with storage time. Rambutan 'Rongrien' fruits tolerate radiation doses up to 900 Gy. A quality test on 'Red Fuji' apples showed that the firmness decreased significantly from 990 Gy but the fruits were tolerant up to 825 Gy.

### 4.2.7 Development of Generic Irradiation Doses for Phytosanitary Treatment of Mealybug Spp. Infesting Agricultural Commodities

Ms Ranjana SETH – India (Research Contract 15852)

The results were summarized in tabular form.

In *Phenacoccus solenopsis* the sterilizing dose required for gravid female was more than the lethal dose for N3 female, whereas for the other two species sterilizing dose was less than lethal dose. *Paracoccus marginatus* gravid female was the most radiosensitive among other species in terms of inducing sterility.

| CHARACTERISTICS | *Phenacoccus solenopsis* | *Maconellicoccus hirsutus* | *Paracoccus marginatus* |
|---|---|---|---|
| 1. (a) most radioresistant pre-imaginal stage<br>(b) $ED_{99.9}$ for metamorphic inhibition | $N_3$ female<br>340 Gy | $N_3$ female<br>371 Gy | $N_3$ female<br>258 Gy |
| 2. Effective dose inducing near complete sterility in adults derived from treated immature stages | N1- 25.7 Gy<br>N2- 27.3 Gy<br>N3 female-35.5 Gy | N1- 40.4 Gy<br>N2- 62.7 Gy<br>N3 female – 88 Gy<br>N3 male- 65.5 Gy<br>N4 male- 84.5 Gy | N1- 31.4 Gy<br>N2- 38.8 Gy<br>N3 female – 62.4 Gy<br>N3 male- 41.4 Gy<br>N4 male- 55.1 Gy |
| 3. $ED_{99.9}$ for inducing near complete sterility for different age groups of females | 0-1day- 52 Gy<br>5-6 day- 138 Gy<br>11-12 day- 374 Gy | 0-1 day- 112 Gy<br>3-4 day- 160 Gy<br>6-7 day- 235 Gy | 0-1 day- 55 Gy<br>3-4 day- 81 Gy<br>6-7 day- 165 Gy |
| 4. Gamma dose for nearly complete check in $F_1$ female adult formation (in consequence to sub sterilization of parent mealy bugs) | 0-1 day (female)- 36 Gy<br>5-6 day (female) - 55 Gy<br>11-12 day (female)- 79 Gy | 0-1 day (male)- 55 Gy<br>0-1 day (female)- 39 Gy<br>3-4 day (female)- 57 Gy<br>6-7 day (female)- 82 Gy | 0-1 day (male)- 34 Gy<br>0-1 day (female)- 35 Gy<br>3-4 day (female)- 43 Gy<br>6-7 day (female)- 61 Gy |
| 5. Sub sterilization dose (to $P_1$ female mealy bug) for nearly complete $F_1$ sterility | 0-1 day (female)- 26 Gy<br>5-6 day (female)- 35 Gy<br>11-12 day(female)- 57Gy | 0-1 day (male)-36 Gy<br>0-1 day (female)- 30 Gy<br>3-4 day (female)- 39 Gy<br>6-7 day (female)- 52Gy | 0-1 day (male)- 27 Gy<br>0-1 day (female)- 28 Gy<br>3-4 day (female)- 30 Gy<br>6-7 day (female)- 37 Gy |

### 4.2.8 Generic Dose of Gamma Irradiation for Quarantine Treatment of Mangosteen Insect Pests

Mrs Murni INDARWATMI - Indonesia (Research Contract 15808)

Mangosteen is a praised Indonesian fruit but exports are still limited due to phytosanitary barriers. The fruit was found to carry five species of mealybugs: 1) *Pseudococcus cryptus* Hempel, 2) *Exallomochlus hispidus* Morrison, 3) *Dysmicoccus neobrevipes*, 4) *D. brevipes*, 5) *Rastrococcus spinosus*. Their presence results in economic losses due to indirect effects such as black sooty moulds growth on deposits of honeydew produced on leaves and fruits surfaces. This affects photosynthesis and reduces fruit quality.

All species were reared on Kaboca squash and placed into plastic containers of various sizes stored at 25 ±2 $^{o}$C, RH 80 ±5%. The plastic containers were covered with muslin to prevent the mealybugs from escaping. The crawlers being highly mobile, different species of mealybugs were placed on different racks. The mealybugs were irradiated to identify the most radiotolerant life stages and to determine the minimum dose that could be used as a phytosanitary treatment.

Doses of 60, 80, 100 and 120 Gy were used for *E. hispidus* in order to determine the minimum dose to sterilize the adults. Dose response curves estimated that a minimum dose of 111 Gy was necessary to totally sterilize adults of *E. hispidus*. A dose of 100 Gy produced 71 % survival of *P. cryptus* after irradiation, but with an extra 100 Gy there was no progeny. Further tests will therefore be carried out using lower doses. The most tolerant stage is the adult. The DUR values ranged from 1.26 to 1.29 (over dose range from 150 to 600 Gy).

Irradiation above 250 Gy had a negative effect on the firmness and the sepal freshness of mangosteens. However irradiation delayed by 7 days changed the required dark brown colour.

### 4.2.9 Effect of gamma irradiation treatment on the quality of mamey sapote (*Pouteria sapota*); Gamma irradiation as phytosanitary treatment for the control of white mango scale (*Aulacaspis tubercularis*); The use of X ray irradiation as a phytosanitary treatment for oranges.

Mr Yeudiel GOMEZ SIMUTA - Mexico (Research Contract 16037)

The mamey fruit (*Pouteria sapota*) is native to México and Central America. It is cultivated in different regions of México, the state of Chiapas being one of the principal producers. However, high infestations by fruit flies, specifically *Anastrepha serpentina* (Wiedemann) severely restrict commercialization. Not all quarantine treatments can be applied to mamey fruits. Methyl bromide and forced heat are the two principal phytosanitary treatments used for mamey fruit but alternative methods are desirable given the health and environmental problems associated with the use of fumigants. The effects of gamma irradiation on the quality of *Pouteria sapota* were studied. The results showed that doses from 150 to 300 Gy can be used as phytosanitary treatment without any effect on the organoleptic characteristics of the fruit. The results also showed that the irradiation treatment did not have any adverse effect on weight loss, internal color, pH, total soluble solids, firmness and enzymatic activity (poliphenoloxidase).

The hot water treatment has been used in Mexico as a quarantine treatment for Mexican mangoes but the number of packers using this treatment is insufficient to meet the demand for mango producing areas. In recent studies, we have shown that a gamma irradiation treatment can be used as a phytosanitary measure without any significant effects on the product quality. In this last phase of the project we focussed on the use of irradiation at doses from 150 to 500 Gy to control the mango white scale (*Aulacaspis tubercularis*) since mango is of great economic importance. Our results demonstrated that all evaluated doses prevented the development of the scale. Studies on the capacity of the gamma irradiation treatments to eliminate this species are still on going, but we are confident that a dose will be obtained. Finally, in order to look an

alternative irradiation method that could be used as phytosanitary purposes, doses of 150, 300, 400 and 500 Gy of X ray irradiation were evaluated in orange, and the effect of the doses on the organoleptic characteristics of the fruit were determined. In conclusion, these studies indicated that X ray irradiation treatments for disinfesting oranges did not produce any significant changes in quality, flavor and acceptance by the consumers. X ray irradiation doses up to 500 Gy can be used for quarantine treatment in orange.

### 4.2.10 Irradiation as Phytosanitary Treatment for the Control of Citrus Psyllid *Diaphoronia citri* and Scale Insects

Mr Inamullah KHAN - Pakistan (Research Contract 16894)

Citrus and mangoes are the main two export fruits from Pakistan, which has adopted the USDA-APHIS dose of 400 Gy for all fresh agricultural commodities.

Mango scale, *Aspidiotus destructor* Signoret (Hemiptera: Diaspididae) is a quarantine pest of mango and many other tropical crops. Irradiation was examined as a potential phytosanitary treatment to control mango scale. Dose response tests were conducted with eggs, 1$^{st,}$ 2$^{nd}$ stage nymphs and 3$^{rd}$ stage adult females without eggs, and with eggs at a series of irradiation doses between 100 and 300 Gy to determine the most tolerant stage. The 3$^{rd}$ stage adults were the most tolerant stage. From a log dose analysis a dose of 217.7 was estimated as an effective dose to completely stop scale development to the next stages. In large-scale validation tests approximately 40,531 scales were tested for 200 Gy and 51,101 for 220 Gy (total= 91,631) scales with all stages. The scales exposed to 220 Gy did not develop further. Irradiation treatment with a minimum absorbed dose of 220 Gy should provide quarantine security for mango scale on exported commodities.

Citrus red scale**,** *Aonidiella aurantii* (Hemiptera: Diaspdidiae) is a quarantine pest of citrus. The minimum dose required to inhibit normal adult emergence of the most tolerant stage was determined. Dose response tests were conducted with first, second stage nymphs and pre-oviposition females at a series of irradiation doses range between 100 to 300 Gy. Eggs and 1$^{st}$ instars nymphs were susceptible to irradiation with predicted doses of 146 Gy and 168 Gy respectively. Second stage nymphs were completely inhibited with a dose of 210 Gy. Third stage adults were the most tolerant stage and a dose of 219 Gy was estimated to cause complete inhibition of *A. aurantii.* Validation tests showed that a dose of 220 Gy was sufficient for phytosanitary treatments.

Eggs, nymphs and adults of Citrus psyllid **(***Diaphornia citri*) were exposed to a series of gamma irradiation doses ranging from 100 to 300 Gy and examined for post irradiation mortality and development to the next stage. A dose of 146 Gy was calculated to prevent egg hatching. A dose 151 Gy was sufficient to stop further development of 1$^{st}$ and 2$^{nd}$ instar nymphs. The 3$^{rd}$ and 4$^{th}$ instar nymphs were more tolerant and a dose of 187 was predicted to prevent their further development. Adult females were the most resistant stage and a dose of 864 was estimated for their complete mortality. Assessment of female fecundity was not possible because none of the female's including control laid eggs during the experiment.

Biochemical investigations of irradiated kinnow citrus fruit showed that no significant weight loss occurred in both waxed and unwaxed fruit. Significant increase in acidity with storage and dosage was noted. Insignificant increase in TSS was also noted. Vitamin C content decreased with storage time and dosage but both were insignificant. Post-treatment fruit appearance, taste, firmness were also within the acceptable range.

### 4.2.11 Evaluating Gamma Irradiation as a Post-Harvest Treatment for the Control of Citrus Mealybug and False Codling Moth

Hendrik HOFMEYR - South Africa (Research Contract 15634)

Eggs, 1st-3$^{rd}$ instar nymphs, as well as pre-oviposition and oviposition females of citrus mealybug *Planococcus citri* were reared on butternut *Cucurbita moschata* Duchesne (Cucurbitales: Cucurbitaceae).

The stages were consecutively treated in situ with a range of ionizing irradiation doses from 50-400 Gy. The object was to establish a dose that would prevent all treated stages from producing an F1 progeny. Efficacy of a 150 Gy dose was confirmed for the most tolerant stage, viz. oviposition females at a level that exceeded probit-8.7 by a factor of approximately 2.3, viz. 70 431 individuals. The efficacy of 150 Gy was also confirmed for the vine mealybug *P. ficus* on 10 000 oviposition females.

Post-harvest phytosanitary disinfestation of false codling moth *Thaumatotibia Leucotreta* (Lepidoptera: Tortricidae) in citrus fruit.

Tolerance of eggs and larvae to ionizing radiation:
Doses of 40-200 Gy radiation were assessed on 24-96 h old eggs and 1st to 5th instar larvae of *Thaumatotibia leucotreta* to establish the lowest effective dose capable of preventing the development of larvae and pupae, or totally suppressing flight ability and/or reproduction of moths. The eggs and larvae were increasingly radiotolerant as they developed and were most resistant at 96 h and 5th instar respectively. The flight ability, oviposition and fertility of moths developing from treated 96 h old eggs were prevented at respectively 70 Gy, 50 Gy and 40 Gy. A dose of 150 Gy increased the mortality of pupae and moths from treated 5th instar larvae. Flight ability could not be suppressed with doses up to 70 Gy. The fecundity and fertility of subsequent moths were completely inhibited at 70 Gy and 60 Gy respectively. This necessitated the use of well-developed eggs and larvae in subsequent studies.

Relative tolerance of larvae in synthetic diet and oranges to ionizing radiation:
The relative effects of ionizing radiation on the general developmental performance of larvae reared and treated in artificial diet were compared to that of feral larvae developing and treated in naturally infested oranges. A mean dose of 40 Gy was used to treat larvae from both sources. The mortality of larvae and pupae were very similar in rearing jars and oranges. The fecundity of moths from both larval sources was not significantly different, but moths from artificially reared larvae were significantly more fertile than their feral counterparts. The former larvae were therefore used to evaluate a probit-9 level efficacy of ionizing radiation as a phytosanitary treatment for *T. leucotreta*. A total of 124 493 5th instar larvae were treated with 100 Gy. The treatment reduced the subsequent numbers of pupae and moths by up to 85.6% relative to the untreated control. None of the moths was able to fly. The gender ratio of the moths developing from treated larvae was predominantly male-based with a female to male ratio of 1:2.4, compared with the untreated control ratio of 1.2:1. Mating was reduced by 83.3%. The moths were totally infertile and no eggs were produced. These results successfully validated the probit-9 level efficacy of 100 Gy of ionizing radiation for phytosanitary treatment.

Determination of Ionizing Radiation and Cold Treatment Conditions for Inclusion in a Combination Treatment:

The effects of 40-70 Gy doses of ionizing radiation and cold treatments of 0.6-7.0°C for periods of 10-22 days by themselves and in combination, were assessed on 5th instar larvae in artificial rearing medium. It was demonstrated that the two methods can act together to potentially provide adequate control, with the prospect of reduced fruit quality effects due to the reduced intensity of the component treatments. A combination treatment consisting of 60 Gy ionizing radiation followed by 16 days at 2.5°C was identified for validation as a combination treatment at the probit-9 level of efficacy.

A total of 104 617 mature, 5th instar larvae was treated. Larval mortality was 99.7% and 50.2% of the subsequent pupae died. A total of 143 moths with a gender ratio of 1 female to 7.9 males eclosed. Only 4.8% of the moths were able to fly. No eggs were produced by the moths in mating studies. The probit-9 level efficacy of the combination treatment was validated, indicating that it meets the efficacy requirements for utilization as a phytosanitary disinfestation treatment for *T. leucotreta* in citrus fruit in international trade.

### 4.2.12 Irradiation as a Phytosanitary Measure for Grapes Infested with the Grape Vine Moth, *Lobesia botrana* and Commodities Infested with the Khapra Beetle, *Trogoderma granarium*

Mr Mohammed MANSOUR - Syrian Arab Republic (Research Contract 15574)

The grape vine moth, *Lobesia botrana*, is a key pest on grapes in Syria and causes millions of dollars in losses every year. The khapra beetle, *Trogoderma granarium*, is a destructive pest of stored agricultural products. Both species are of quarantine importance in many countries of the world, which makes it necessary to effectively treat exported products which are potential carriers of these two species. Ionizing radiation has been recognized as a potential alternative to the use of methyl bromide as a phytosanitary treatment. Determining the irradiation dose that guarantees complete death of the irradiated insects (or ≥ sterility) without any unacceptable effects on the treated commodity is necessary. Information on the effects of gamma radiation on the grape vine moth is lacking and information on the khapra beetle needs to be reconfirmed. Results of these studies showed that 200 Gy is a sufficient dose to prevent hatch of the F1 eggs of the grape vine moth and 100 Gy prevents adult development of all immature stages of the khapra beetle.

### 4.2.13 Generic Irradiation Dose to Provide Quarantine Security for Leafminers (*L. sativa, L. trifolii* and *L. huidobrensis*) and the Effect of Irradiation on Pea Seed

Ms Berna OZYARDIMCI - Turkey (Research Contract 15644)

The objective of this work was to provide data to develop a generic irradiation dose for quarantine treatments of agromyzid leafminers using 3 species of the genus *Liriomyza* and to study the effects of gamma radiation treatment on physical, chemical, and sensorial properties of pea seeds *(Pisum sativum* L). The late pupae were treated with Co-60 gamma radiation at 80, 100, 120, 150 and 180 Gy.

The measure of efficacy used was the prevention of F1 mine formation in leaves. *L. sativa, L. trifolii* and *L. huidobrensis* were found to have similar responses to the dose treatments, with the same dose (150 Gy) preventing the formation of F1 mines. At lower doses, offspring were developed (80, 100 Gy and 120 Gy). Doses of 150 Gy and 180 Gy prevented formation of F1 mines. Confirmatory experiments were undertaken using large numbers of leafminers irradiated to a dose of 150 Gy**.** These confirmatory experiments were carried out on samples having all 3 species *L. sativa, L. trifolii* and *L. huidobrensis* for a total of more than 30,000 insects (10,583 for *L. sativa,* 10,280 for *L. trifolii* and 10,419 for *L. huidobrensis*). This method was adopted as the 3 species were found to have an equal dose response as measured by the efficacy of the prevention of F1 mine formation.

The radio-tolerance of the commodity (pea plants) was studied to ensure that the irradiation treatment has no significant adverse effect on the produce. Pea samples were irradiated at insect disinfestations dose levels with doses of 0.25, 0.5 and 1.0 kGy using a cobalt-60 irradiator and were tested for vitamin C, total carotenoids, protein secondary structure, colour and sensory properties. The pea seeds were not significantly affected by a dose up to 1.0 kGy.

### 4.2.14 Development of Generic Irradiation Doses for Quarantine Treatments Using E-Beam. X ray and Gamma Irradiation

Mr Suresh D. PILLAI and Mr Carlos BOGRAN - USA (Agreement Holder 15638)

Since Mr. Bogran has left the university, another scientist from the university's Entomology Department is being recruited to join the research activities. A number of project tasks were completed to ensure that the research findings from the CRP find immediate commercial acceptance.

This report details the activities that were pursued to accelerate the expansion of phytosanitary treatment by irradiation. There are framework equivalency agreements for the imports of agricultural commodities treated by irradiation into the US. The countries that can export commodities by irradiation include Mexico, India, Thailand, Ghana, Malaysia, Pakistan, S. Africa, and Vietnam. The USDA-APHIS rule was changed in 2012

to allow for the irradiation treatment to take place anywhere in the continental United States. There has been commercial interest especially from Mexico and Pakistan about the possibility of importing untreated commodities and having the consignments treated at the eBeam facility of the National Center for Electron Beam Research (NCEBR) at Texas A&M University. To facilitate this, the NCEBR applied for a USDA-APHIS Facility Certification permit. To achieve this, the facility had to perform a number of specific dose mapping exercises, documentation of facility procedures, development of SOP for important commodities, etc. The USDA-APHIS personnel visited the facility in 2012 and 2014 and certified the facility per the stipulations. The facility has now been approved for phytosanitary treatment for export, import and interstate quarantine treatment. In parallel to the facility certification activities, the NCEBR also was involved in providing technical assistance to the private industry to build businesses to expand the application of eBeam technology in the food industry. To this end, Efoods Imports (http://efoodsimports.com/) a fresh produce import-export company based in Houston, Texas was formed in 2013 in order to focus solely on the trans-border shipments of fruits and was established in 2013. Similarly, another Texas based company, Guayafina Imports, LLC., involved in trans-border shipment of agricultural commodities has started developing packaging and performing dose-mapping studies. Currently, customized packaging for Mexican mangoes and guavas has been completed. Commercial scale eBeam irradiation processes that satisfy USDA-APHIS guidelines and stipulations for mangoes and guavas are now complete and ready for commercial adoption.

Strategies to enhance the economic value of E-Beam treated fresh produce include emphasizing product quality (avoiding chemicals, shelf-file extension), collateral reduction (ca. 3-log) of bacterial pathogens, ability to grade fruit in customized packaging and customized packaging for single / family food service establishment sizes.

### 4.2.15 Exploring the Effects of Controlled Atmospheres on Insect Stress Physiology and the Efficacy of Irradiation Treatments for Insect Control

Mr Daniel HAHN - University of Florida - USA (Agreement Holder 15661)

Many commodities are transported in modified or controlled atmospheres with low oxygen content and/or high carbon dioxide content. Irradiation in low oxygen may affect treatment efficacy, a potential challenge for developing generic irradiation doses. We assessed whether modified atmospheres alter the effective doses needed to successfully prevent adult emergence or sterilize the cabbage looper, *Trichoplusia ni*.

We used atmospheres with 5 oxygen concentrations ranging from complete anoxia to normal atmospheric oxygen (0,5 kPa, 10 kPa, 15 kPa, and 21 kPa) balanced with $N_2$ after removing $CO_2$. In these chambers, we exposed last-instar *T. ni* larvae to one of 5 irradiation doses (0, 50, 100, 150, and 200 Gy) using a 5 MeV electron-beam irradiator in X ray mode, then scored for adult emergence. There was no difference in adult emergence between atmospheres at 0 Gy and adult emergence was prevented in all atmospheres at 200 Gy. At the intermediate doses of 100 and 150 Gy there was substantially more adult emergence from anoxia-treated larvae, but the other atmospheres did not differ in emergence. For larvae, intermediate values of hypoxia between 20 kPa and 5 kPa $O_2$ had no effect on irradiation susceptibility, but anoxia substantially enhanced adult emergence compared to all other atmospheres tested.

We treated the most tolerant stage, pharate adults (a.k.a., late pupae) in all 5 atmospheres above at 0, 200, 400, 600, and 800 Gy using a 5 MeV electron-beam irradiator and scored for adult emergence and fertility. Adult emergence was high up to 400 Gy regardless of atmosphere. At the higher doses, 600 and 800 Gy, pharate adults treated in anoxia had substantially greater emergence than those treated in other atmospheres. Amongst the other atmospheres there were no differences in emergence at 800 Gy, but at 600 Gy the 5 kPa $O_2$ treatment group had higher emergence than the 21kPa $O_2$ group, showing a slight effect of hypoxia. When considering adult fertility as a metric for irradiation success, there was no effect of atmosphere on fertility in non-irradiated females. There was no fertility at 800 Gy in any atmosphere and fertility was very low and not different across atmospheric treatments at 600 Gy. Atmospheric effects were apparent at the 200 and 400 Gy doses wherein anoxia-treated moths had the greatest fertility after irradiation and the normoxia (21 kPa) and 15 kPa oxygen-treated groups had substantially lower fertility. The groups of pharate adults irradiated at 200

and 400 Gy in 5 kPa and 10 kPa oxygen atmospheres were intermediate in fertility between the normoxic and anoxic groups, but were not statistically distinguishable from either. Effects of anoxia on irradiation tolerance were greater than any of the hypoxic atmospheres tested down to 5 kPa oxygen, thus it may be possible to safely accept irradiation as a phytosanitary treatment in modified or controlled atmospheres down to 10 kPa $O_2$, but more work is needed at lower levels of hypoxia between 0 and 10 kPa oxygen.

### 4.2.16 Effects of Gamma Irradiation at Quarantine Doses on Three Species of Mealybugs (Hemiptera: Pseudococcidae) Infesting Red Dragon Fruits

Ms Thi The DOAN - Viet Nam (Research Contract 15635)

During the period from 2010 to 2014, research was conducted on three species of mealybugs: *Dysmicoccus neobrevipes, Planococcus lilacinus* and *Planococcus minor* (Beardsley) (Hemiptera: Pseudococcidae). Female adults were determined as the most radio-tolerant stage in all three species. Target doses to prevent reproduction of adult females and prevent F1 1$^{st}$ instars from molting to 2$^{nd}$ instars were 200 Gy, 150 Gy and 100 Gy for *D. neobrevipes*, *P. minor* and *P. lilacinus*, respectively. Among three mealybugs, *D. neobrevipes* was determined the most radio-tolerance species. Large-scale tests were performed to confirm a required efficacy dose to sterilize adult female *D. neobrevipes* with number of estimated individuals at 31,750. All tests were irradiated at a minimum target dose of 200 Gy. The measured dose range was from 206.4 to 231 Gy by using Fricke dosimeters. Level of efficacy sterility of *D. neobrevipes* was 99.9906 at the confidence level of 95% (all 1$^{st}$ instars that emerged from eggs of 31,750 irradiated female adults died before reaching the 2$^{nd}$ instar). Because *D. neobrevipes* is the most radio-tolerance species, a minimum absorbed dose of 231 Gy will prevent development of F1 1$^{st}$ instars into 2$^{nd}$ instars of *Dysminococcus neobrevipes*, *Planococcus lilacinus*, and *Planococcus minor*. A proposed dose of 231 Gy for *Dysmicoccus neobrevipes*, *Planococcus lilacilus* and *P. minor* (Hemiptera: Pseudococidae) has been submitted to the IPPC via the National Plant Protection Organization of Vietnam.

Further researches showed that gamma irradiation dose rate could affect reproduction and fecundity of female D. neobrevipes (fecundity decreased with increasing radiation dose rate). None of F1 1st nymphs survived and developed into the 2nd nymphs even at the lowest rate of 0.286 kGy/h.Typical commercial storage conditions (10 ±1°C; 85-90% RH) could strongly affect mortality and fecundity of female adults. In these conditions, we observed that the mortality of females steadily increased and reached 100% after 4 weeks. None of 1$^{st}$ instars produced by irradiated females as well as by un-irradiated ones could survive to develop into the 2$^{nd}$ instars after 15 days.

Irradiation doses of 600-800 Gy decreased significantly the firmness and vitamin C content of dragon fruit and changed the appearance of fruits after 3 weeks in storage at 10± 1°C and relative humidity of 85-90%.

### 4.2.17 Research Activities Regarding the Use of Irradiation as Phytosanitary Treatment for Fruit from Uruguay

Anibal ABREU – Uruguay (Research Contract 17062)

The work started in 2012 only so only partial results are available. Uruguay exported citrus to the US for the first time in 2011 using cold treatment as a phytosanitary measure. Irradiation of citrus fruit is being considered for quarantine purposes. No significant effects were found on peel color, firmness and vitamin C in Valencia and Ortanique oranges. Work is currently being carried out on the effects of irradiation on *Xanthomonas citri* spp on symptomatic citrus fruit. Work is also being done to assess the commercial and organoleptic quality of citrus fruit at different doses of irradiation and its effect on the control of *Penicillium digitatum* in mandarin "Afourer" (*Citrus reticulata* Blanco) and *Elsinoë* spp in citrus intended for export. Another programme is the study of the effects of irradiation on blueberries treated for quarantine purposes. Organoleptic tests showed no difference between treatments, and storage time did not affect its acceptance 7 days after irradiation. Irradiation as a quarantine treatment is being evaluated for codling moth (*Cydia pomonella*) in apples and pears intended for export.

## *4.3 Review of CRP Results*

The purpose of this project was to develop and validate irradiation treatment doses for groups of arthropods of quarantine significance moving in international trade. The project comprised 19 participant institutes and organisations from 15 countries and has generated treatment data on 37 arthropod species covering five orders of insects and three families of mites plus one phytophagous snail. Details are given in Annex 3.

The principal aim of the CRP was to generate data in support of generic quarantine irradiation treatments, particularly for certain 'data-deficient' groups of major quarantine pest importance, such as thrips, mealybugs, scale insects, spider mites and so on. The results will also be formulated by members of CRP in conjunction with their own NPPO so that treatment submissions can be proposed for consideration as annexes to ISPM28 (Phytosanitary Treatments for Regulated Pests).

In all respects, the objectives of the project were fully achieved, and generic irradiation treatments for a number of important pest groups (e.g. tortricid moths and mealybugs) were obtained. When fully implemented, the results of this CRP should result in generic phytosanitary doses for more than 50% of all regulated pest species.

Large scale confirmatory tests enabling the setting of effective treatment doses (e.g. >99.99% at the 95% confidence level) were conducted on 13 pest species and it is envisaged that these data will be incorporated into revised generic irradiation treatments, for example for: i) all insects; ii) eggs and larvae of Tortricidae and iii) Pseudococcidae. These generic treatments will be submitted for consideration by the IPPC treatments panel (TPPT). To specifically address this issue, this CRP included a number of past and present members of the TPPT, which enabled the research to closely focus on addressing the concerns of this panel.

A secondary objective of the CRP was to examine the effects of low oxygen commodity storage and dose rate on efficacy and commodity tolerances. A number of in vitro studies were carried out in the CRP investigating the effect of low oxygen atmospheres on the efficacy of irradiation. The CRP concluded that in general, complete anoxia has the greatest effect on the results of irradiation, but preliminary research showed that current modified atmosphere packaging (MAP) may not produce sufficiently low oxygen levels to reduce the treatment efficacy. Investigation into the negative effects of low oxygen led to the hypothesis that increased oxygen levels might increase efficacy, potentially leading to reduction in dose. Preliminary research demonstrated that is possible, but further research is needed to evaluate whether there are any negative effects in terms of product quality.

Another interesting output was the finding that cold treatments can be successfully used in combination with irradiation treatments. Whilst further research is needed, it was found that combining cold temperature and irradiation treatments can be synergistic, lowering the required irradiation dose. Furthermore, many of the findings of this CRP have proven that lower irradiation doses than those currently accepted could be utilised in commercial treatments. For example, the generic PI dose approved by some NPPO's of 400 Gy (for all insects except pupae and adult Lepidoptera) could be decreased to 250 Gy based on findings of the CRP. The benefits of being able to use lower treatment doses are particularly important in commercial irradiation facilities where the dose range within the product can be relatively broad. Treatments targeting a reduced minimum dose help reduce the maximum dose received by the product and therefore ensures that fruit quality is maintained by using low intensity irradiation and it can also help optimise the commercial treatment process.

Finally, the CRP generated a great deal of supplementary data on quality effects of different forms of irradiation on traded fruits. The results are summarized in Annex D. In general, there were no significant effects on the nutritional status of irradiated fruits at doses used for phytosanitary purposes.

The international trade of produce which has been irradiated for phytosanitary purposes is growing rapidly. Volumes of irradiated consignments have more than doubled over the duration of this project. Seven countries (Australia, India, Mexico, South Africa, Thailand, USA and Vietnam) have irradiation facilities that are being used for phytosanitary treatments.

Finally, the first RCM emphasised the importance of proper dosimetry methods and their reporting. The reports presented during the subsequent RCMs demonstrated that the participants had acquired a greater understanding of the importance of this key parameter (and the need to work with their dosimetry service to obtain such data) in terms of irradiation research and its implication for commercial use.

## *4.4 Publication of the CRP Results in a Special Issue of a Journal*

As discussed at the 3rd RCM, it has been agreed to publish the results of the CRP in a special issue of The Florida Entomologist. Agreement in principle has been received from the journal editor, Mr Waldemar Klassen, and the IAEA already has a specimen contract with the journal from a prior special issue. The internal procedures will be started without delay.

The participants have produced 37 papers and one short note in preparation. In addition, there will be an introductory review paper and it was proposed that four additional reviews be prepared by groups within the CRP on Pseudococcidae, Tortricidae, scale insects and the overall 400 Gy generic dose for all insects other than pupae and adults of Lepidoptera. The total page count is estimated to be about 250.

It was agreed that participants would submit their manuscripts by 1st December 2014 to the Agency for review and compiling into the special issue. Mr Guy Hallman, who will be moving to the laboratories in Seibersdorf later this year, has agreed to act as the coordinator for the production of the special issue and to lead the group on the 400 Gy generic dose review. Ms Celina Horak, Mr Yeudiel Gómez Simuta, Mr Anibal Abreu and Mr Valter Arthur (Portuguese) have volunteered to assist with providing Spanish and Portuguese translations of abstracts, as required by the journal.

## *4.5 Outputs*

- Data on applications of irradiation on pests of quarantine significance:
  The total number of species studied is 38 in 14 families in 5 orders of insects, 3 families of mites and one snail.
- Validation of irradiation doses for the quarantine treatment of specific insect species.
  The number of large scale confirmatory tests (tens of thousands of insects) was done for 16 species (Vietnam: 3, China: 2, USA: 1, Brazil: 1, Argentina: 1, South Africa: 3, Pakistan: 2, Turkey:3).
- Determination of the effect of low oxygen gas content (i.e. modified atmosphere storage) and dose rates on irradiation efficacy.
  There were a limited number of studies. *In vitro* studies undertaken within this project have indicated that low oxygen may lower the efficacy of irradiation. Conversely, some work showed that high oxygen content may increase efficacy.
  Previous studies indicate that low oxygen will not be an issue with tephritids but it could be an issue with other arthropods.
- The effects of irradiation on the sensory and nutritional attributes of 24 fresh commodities were studied. At least 16 commodities were not significantly affected by doses that they would receive in a commercial irradiator (≥ 800 Gy).
- An additional output is the finding that cold treatment (2.5°C during 16 days after irradiation) has a synergistic effect with irradiation, the efficacy dose on the false codling moth (*T. leucotreta*) being lowered from 100 to 60 Gy.
- Two participants examined dose rate effects with inconclusive results. The issue might be more complicated than initially thought and would require further research.
- Nineteen papers were already published or submitted in the course of the project. They are listed in Annex E. Another 30-35 will be submitted to *The Florida Entomologist* for a special issue. This open access publication will fully address the issue of communication to a wider scientific audience.
- Some of the participants submitted abstracts to the Scientific Committee of the IAEA Food Safety and Quality Symposium to be held in November 2014 in Vienna.
- Some of the results are adequate for proposal as treatment schedules to the IPPC.

## *4.6 Outcomes*

- Greater appreciation of dosimetry requirements and reporting by non-specialists.
- Development of treatments based on the results of the CRP approved by PPOs.
- Additions to International Standards for Phytosanitary Measures, including ISPM 28 on Phytosanitary Treatments for Regulated Pests.
- Accelerated the development of a certified electron beam process for phytosanitary irradiation.
- Increased exports towards high value markets of fruit produced in developing and developed countries.
- Lowered trade barriers by addressing quarantine requirements for insect pests.
- Contributed to the acceptability of irradiated produce by confirming that there is no or minimal effect on their nutritional quality.
- Greater scientific knowledge and understanding of phytosanitary irradiation.

# 5. Conclusions and Recommendations of the Fourth and final RCM

## *5.1 Conclusions*

1. By allowing participants from 15 different countries to share expertise and results towards a common goal, the CRP was an excellent example of international collaboration.

2. The objectives of the CRP were fully met. Thirty-eight different pest species were studied of which thirteen were fully completed using very large numbers of insects in confirmatory tests, to validate treatment efficacy at levels of phytosanitary security commonly used internationally.

3. Two treatments for *O. nubilalis* and 3 species of mealybugs are at an advanced stage of the International Plant Protection Convention (IPPC) approval process.
   Other generic and species specific treatments have been developed as a result of this CRP that will be submitted at the next IPPC call for treatment proposals.

4. Due to the strong emphasis placed on dosimetry at the start of the CRP, participants have recognized the importance of good dosimetry practices and implemented improved procedures to measure and report doses.

5. The presence of observers at the meeting generally enriched the discussions.

## *5.2 Recommendations*

1. In order to develop more generic treatments further research is required on
   - scale insects;
   - mites;
   - whiteflies;
   - weevils;
   - Lepidoptera.

2. More research is needed on the effects of both low and high oxygen concentration in modified atmosphere packaging.

3. The possibility that irradiation can be used to prevent pathogen transmission by insect vectors should be investigated.

4. The possibility of an additive or synergistic effect resulting from combined treatments such as irradiation and cold treatment should be investigated as they could lead to less detrimental effects on

the commodity.

5. The use of phytosanitary irradiation as an alternative to methyl bromide should be considered for cut flowers and forestry products.

6. The Agency is encouraged to examine how the commercial use of phytosanitary irradiation can be fostered in the Latin America region, given the commercial opportunities and the large amount of research on irradiation that has already taken place.

7. Participants are encouraged to build on the professional network developed during this CRP to further establish the commercial use of phytosanitary irradiation. They are also encouraged to create or strengthen links with national counterparts at National Plant Protection Organizations (NPPO).

8. Participants are encouraged to become involved in the IPPC-sponsored Phytosanitary Treatment Expert Group to pursue further research and implementation of PI.

# 6. Logical Framework

## *6.1 Activities*

| Activity | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| Advertise the CRP (December 2008). Receipt of research contract and agreement proposals. Award contracts and sign agreements by end April 2009. | X | | | | | |
| Organise 1st RCM (July/August 2009) to discuss overall CRP work plan, agree on research protocols, governance, quality assurance, record keeping and reporting. | X | | | | | |
| Award Research Contracts | X | | X | | | |
| Phase 1: 18 months' work programme | X | X | | | | |
| Organise 2nd RCM in March/April 2011 to review the work conducted in Phase 1 based on progress reports and presentations. Develop the detailed work plan for Phase 2 and ensure that the CRP objectives are met. | | | X | | | |
| Phase 2 : Work programme | | | X | X | | |
| Organise 3rd RCM (Oct 2012) to review work conducted in Phase 2 and agree final phase 3 work programme. | | | | X | | |
| Phase 3: Work programme | | | | X | X | |
| Final RCM<br>Review Phase 3 and global work.<br>Prepare research papers for publication in the special issue of a journal. | | | | | X | X |

## *6.2 Logical Framework*

| | Project Design Elements | Verifiable Indicators | Means of Verification | Important Assumptions |
|---|---|---|---|---|
| **Overall Objective** | Enhance opportunities for international trade in foods of plant origin subject to insect infestation | Decrease in detained/rejected consignments after inspections | Reports to national authorities and regional plant protection organisations | Commitment by all participating partners to report on national data |
| **Specific Objective** | Provide data to develop generic irradiation doses for quarantine treatments for consideration in providing an appropriate level of assurance against insect pest incursions | Monitoring programmes for surveillance of quarantine pests | Reports to national authorities and regional plant protection organisations | Commitment by all participating partners to report on national data |
| **Outcomes** | Generic doses for a range of quarantine pests/commodities adopted by Commission on Phytosanitary Measures | Data and including dose response information published and provided to IPPC Technical Panel on Phytosanitary Measures | Laboratory results and published reports | Acceptance of recommended generic doses by IPPC Member States |
| **Outputs** | Validated generic doses/commodities and protocols recognised, harmonised SOPs | Protocols and SOPs produced | Reports submitted to the IPPC, IAEA, FAO and national authorities | Continued commitment by all partners |
| **Activities** | Consultants meeting | Consultants Meeting report | Meeting report and recommendations | Consultants identified, available and meeting held |
| | Research contract and agreement holders identified; contracts and agreement signed | First RCM | Meeting report and recommendations | Continued commitment by all parties |
| | Work programme to develop and validate dosimetry and research methodology | 1st, 2nd and 3rd RCM | Meeting reports | Continued commitment by all parties |
| | Quality check protocols for generic doses | 3rd RCM | Meeting reports | Continued commitment by all parties |
| | Prepare SOPs, scientific papers and TECDOC. | Final RCM | Meeting reports, TECDOC, SOPs and papers published | Continued commitment by all parties |

**Annex A**

**List of Participants**

| | | |
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**Annex B**

**AGENDA**

# Fourth Research Coordination Meeting (RCM) of CRP D62008 on the Development of Generic Irradiation Doses for Quarantine Treatments

Vienna, Austria
IAEA Headquarter and Seibersdorf Laboratories
2 – 6 June 2014

| **Monday 2 June 2014** | |
|---|---|
| 08:30-09:30 | Registration |
| **Session A: Welcome and Opening** by Carl Blackburn | |
| 09:30-10:30 | Welcome and Opening Remarks |
| | Introduction and presentation of participants |
| | The achievements of the CRP so far.<br>Objectives of this 4th and Final Research Coordination Meeting |
| | Appointment of chair and co-chair |
| | Selection of rapporteur |
| | Adoption of Agenda |
| | Housekeeping notes |
| *10:30-11:00* | *Coffee break* |
| **Session B: Introductory Presentations** | |
| 11:00-11:30 | Update on the commercial use of phytosanitary irradiation<br>Yves Henon - IAEA |
| 11:30-12:00 | Update on The IPPC Technical Panel on Phytosanitary Treatments (TPPT).<br>Andrew Parker - IAEA |
| 12:00-12:30 | Where we stand now with generic phytosanitary irradiation treatments<br>Guy Hallman - USA |
| *12:30-13:30* | *Lunch break* |
| **Session C: Participants Reports** | |
| 13:30-14:15 | Translating generic irradiation doses to USDA-APHIS approved validated processes for eBeam treatment<br>Suresh Pillai – USA |
| 14:15-15:00 | The oxygen effect: physiology to practicalities<br>Daniel Hahn - USA |
| *15:00-15:30* | *Coffee break* |
| 15:30-16:15 | The impact of a 1,000 Gy treatment on fruit quality and nutritional value for a range of fruit and vegetables<br>Peter Leach - Australia |
| 16:15-17:00 | Alanine-EPR dosimetry system for Dose Assurance Service for low-energy X radiation.<br>Kishor Mehta on behalf of Helen Koury - Brazil |

| Tuesday 3 June 2014 | |
|---|---|
| **Session C: Participants Reports** | |
| 09:00-09:45 | Gamma radiation quarantine treatments for different groups of arthropods<br>Celina Horak - Argentina |
| 09:45-10:30 | Post-harvest phytosanitary disinfestation of citrus mealybug and vine mealybug.<br>Post-harvest phytosanitary disinfestation of false codling moth in export citrus fruit from South Africa using ionizing radiation or ionizing radiation and cold treatment combinations.<br>Hendrik Hofmeyr – South Africa |
| *10:30-11:00* | *Coffee break* |
| 11:00-11:45 | Effects of gamma irradiation at quarantine doses on three species of mealybugs (Hemiptera: Pseudococcidae) infesting red dragon fruits.<br>Doan Thi The - Vietnam |
| 11:45-12:30 | Bio-efficacy of ionizing radiation as a phytosanitary treatment against mealy bug species of quarantine importance, viz. *Phenacoccus solenopsis, Maconellicoccus hirsutus* and *Paracoccus marginatus*<br>Ranjana Seth - India |
| *12:30-13:30* | *Lunch break* |
| 13:30-14:15 | Effect of gamma irradiation on the mortality and growth inhibition of *Diaphornia citri, Aspidiotus destructor* and *Aonidiella aurantii*.<br>Dr Inamullah Kahn - Pakistan |
| 14:15-15:00 | Generic irradiation dose to provide quarantine security for agromyzid leafminers<br>Berna Ozyardimci – Turkey *(by Webex)* |
| *15:00-15:30* | *Coffee break* |
| 15:30-16:15 | Effect of gamma irradiation treatment on the quality of mamey sapote (*Pouteria sapota)*<br>Gamma irradiation as phytosanitary treatment for the control of white mango scale (*Aulacaspis tubercularis*)<br>The use of X ray irradiation as a phytosanitary treatment for oranges<br>Yeudiel Gómez Símuta - Mexico |
| 16:15-17:00 | Irradiation as a phytosanitary treatment for peach fruit moth and Jack Beardsley mealybug<br>Zhang Guopin – PR China |

| Wednesday 4 June 2014 | |
|---|---|
| **Session C: Participants Reports** | |
| 09:00-09:45 | Gamma irradiation for quarantine treatment of mealybug on mangosteen<br>Murni Indarwatmi - Indonesia |
| 09:45-10:30 | Irradiation as a phytosanitary measure for grapes infested with the grape vinemoth *Lobesia botrana* and commodities infested with the khapra beetle*Trogoderma granarium*<br>Mohammed Mansour - Syria |
| *10:30-11:00* | *Coffee break* |
| 11:00-11:45 | Partial results on research activities regarding the use of irradiation as phytosanitary treatment for fruit from Uruguay.<br>Anibal Abreu - Uruguay |
| 11:45-12:15 | Report on a proposed IAEA Coordinated Research Project on identification of irradiated insects.<br>Andrew Parker - IAEA |
| 14:15-16:30 | Visit of the Seibersdorf Laboratories |

| Thursday 5 June 2014 | |
|---|---|
| **Session D: Review of results** | |
| 09:00-17:00 | Conclusions on what the CRP achieved<br>Publication of the results in a special journal issue<br>Identification of areas where more research is needed |

| Friday 6 June 2014 | |
|---|---|
| **Session E: Plans for the future** | |
| 09:00-10:30 | Should future research be the object of a new CRP? |
| 10:30-17:00 | Meeting Report |
| *17:00* | *Closing* |

**Annex C**

**Taxonomic groups represented**
**in the**
**CRP on the development of generic irradiation doses for quarantine treatments**

| Class, Order, Family | | | Group Common Name | Species | Nb | Countries |
|---|---|---|---|---|---|---|
| Insecta | Coleoptera | Dermestidae | Dermestid beetles | *T. granarium* | 1 | Syria |
| Arachnida | | Eriophyidae | Eriophyid mites | *P. oleivora*<br>*A. litchii* | 2 | Brazil |
| | | Tetranychidae | Spider mites | *P. citri*<br>*T. urticae*<br>*T. desertorum*<br>*O. ilicis* | 4 | Brazil, China (SCAU) |
| | | Brevipalpidae | Broad mites | *B. phoenicis* | 1 | Brazil |
| Insecta | Diptera | Agromyzidae | Leaf miners | *L. sativae*<br>*L. huidobrensis*<br>*L. trifolii* | 3 | Turkey, USA (USDA) |
| Insecta | Hemiptera | Aleyrodidae | White flies | *T. vaporariorum* | 1 | Argentina, China (CAIQ) |
| Insecta | Hemiptera | Diaspididae | Armored scales | *H. lataniae*<br>*A. aurantii*<br>*A. destructor*<br>*A. tuburcularis* | 4 | Argentina, Mexico, Pakistan, Syria |
| Insecta | Hemiptera | Pseudococcidae | Mealybugs | *Ps. Jackbeardsleyi*<br>*Pa. citri*<br>*Pl. ficus*<br>*Pl. lilacinusand*<br>*Pl. minor*<br>*Pa. marginatus*<br>*Ph. solenopsis*<br>*M. hirsutus*<br>*D. neobrevipes*<br>*E. hispidus*<br>*P. cryptus* | 11 | China (CAIQ), Indonesia, S Africa, Vietnam |
| Insecta | Hemiptera | Psyllidae | Psyllids | *D. citri* | 1 | Pakistan, USA (USDA) |
| Insecta | Lepidoptera | Carposinidae | Carpospinid moths | *C. sasakii* | 1 | China (CAIQ) |
| Insecta | Lepidoptera | Gelechiidae | Gelechiid moths | *E. aurantiana* | 1 | Brazil |
| Insecta | Lepidoptera | Noctuidae | Noctuid moths | *S. frugiperda*<br>*H. virescens*<br>*H. zea*<br>*T. ni* | 4 | Argentina, USA (USDA&UF) |
| Insecta | Lepidoptera | Tortricidae | Tortricid moths | *T. leucotreta*<br>*L. botrana* | 2 | Argentina, S Africa, Syria |
| Insecta | Thysanoptera | Thripidae | Thrips | *F. occidentalis* | 1 | USA (UF&TAMU) |
| Gastropoda | Stylommatophora | Helicidae | Snails | *C. aspersum* | 1 | USA (USDA) |

Total number of species studied: 38 in 14 families, 5 orders of insects, 3 families of mites, one family of snails.

**Annex D**

## Effects of irradiation on the quality of fruit and vegetables

| Fruit common name | Fruit scientific name | Variety | Tolerated dose (Gy) | Radiation | Organoleptic | Appearance | Colour | Firmness | Vitamin C | Total solids | Weight loss | Antioxidants | Acidity | Country | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mango | *Mangifera indica* | Ataulfo | ≥ 500 | G | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | pH | | |
| Mamey | *Pouteria sapota* | | ≥ 300 | G | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | pH | | |
| Oranges | *Citrus sinensis* | Valencia | ≥ 50 | X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | pH | MEX | |
| Oranges | *Citrus sinensis* | Valencia + ortanique Afourel | ≥ 1500 | G | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | pH | | |
| Blueberry | *Vaccinium corymbosum* | | ≥ 150 | G | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | pH | URU | |
| Blueberry | *Vaccinium corymbosum* | 7 varietis | ≥ 450 | G | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | |
| Grapes | *Vitis labrusca* | | ≥ 750 | G | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | |
| Apples | *Malus domestica* | Red delicious | ≥ 800 | G | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | | |
| Pears | *Pyrus commonis* | Packhams Triumph | ≥ 800 | G | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | ARG | |
| Mangoes | *Mangifera indica* | 4 varieties | ≥ 500 | G | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | pH | | |
| Kinnow | *Citrus reticulata* | Blanco | ≥ 500 | G | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | pH | PAK | |
| Dragon fruit | *Hylocereus undatus* | white | ≥ 600 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Rambutan | *Nephelium lappaceum* | Java | ≥ 500 | G / EB | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | VIE | |
| Apples | *Malus domestica* | Red delicious | ≥ 1000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Apricots | *Prunus armeniaca* | Rival | ≥ 1000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Cherry | *Prunus avium* | Stella | ≥ 1000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Honeydew melon | *Cucumis melo* | Galaxy | 400-600 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Nectarine | *Prunus persica var. nectarina* | Artic snow | 400-600 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Peach | *Prunus persica* | Nectarina | ≥ 1,000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Plum | *Prunus domestica* | Black amber | ≥ 1,000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Rockmelon | *Cucumis melo* | Triumph | ≥ 1,000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Strawberry | *Fragaria x ananassa* | Albion | ≥ 1,000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Table grape | *Vitis vinifera* | Flame seedless | ≥ 1,000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Zucchini-scallopini | *Cucurbita peto* | Blacjjack | ≥ 1,000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | AUS | Full nutritional profile |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tomato | *Lycopersicum esculentum* | Gourmet Swanson | ≥ 1,000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Capsicum | *Capsicum annuum* | Plato | ≥ 1,000 | G | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Mangoes | *Mangifera indica* | Gedong | ≥ 600 | G | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | INS | |
| Fuji Apples | *Malus pumila* | Red Fuji | ≥ 825 | EB | | ✓ | ✓ | ✓ | | | ✓ | | pH | PRC | |
| Rambutan | *Nephelium lappaceum* | Rongrien | 900-1200 | G | ✓ | | | ✓ | ✓ | ✓ | ✓ | | ✓ | PRC CAIQ | |
| Satsuma | *Citrus reticulata* | Mandarin shatang | 400-600 | G | | ✓ | | | ✓ | | | | | PRC SAUC | Total sugar |
| Peas | *Pisum sativum* | | ≥ 1,000 | G | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | TUR | Total carotenoids, Protein secondary structure |

**Annex E**

**List of papers published or submitted during the course of the CRP**


Doan Thi The, Nguyen Thuy Khanh, Vo Thi Kim Lang, Cao Van Chung, Tran Thi Thien An, Nguyen Hoang Hanh Thi 2012. Effects of gamma irradiation on different stages of mealybug *Dysmicoccus neobrevipes* (Hemiptera: Pseudococcidae). Radiat. Phys. Chem. 81: 97–100

Hallman, G. J. 2012. Generic phytosanitary irradiation treatments. Radiat. Phys. Chem. 81: 861-866.

Hallman, G. J. 2013. Rationale for a generic phytosanitary irradiation dose of 70 Gy for the genus *Anastrepha* (Diptera: Tephritidae). Fla. Entomol. 96: 983-990.

Hallman, G. J., A. G. Parker, and C. M. Blackburn. 2013. The case for a generic phytosanitary irradiation dose of 400 Gy for Lepidoptera that infest shipped commodities as pupae. J. Econ. Entomol. 106: 525-532.

Hallman, G. J., K. Guo, and T.-X. Liu. 2011. Phytosanitary irradiation of *Liriomyza trifolii* (Diptera: Tephritidae). J. Econ. Entomol. 104: 1851-1855.

Hallman, G. J., V. Arthur, C. M. Blackburn, and A. G. Parker. 2013. The case for a generic phytosanitary irradiation dose of 250 Gy for Lepidoptera eggs and larvae. Radiat. Phys. Chem. 89: 70-75.

Ke Zhang, Yueye Deng, Haohao Fu, Qunfang Weng, et al. 2014. Effects of Co-60 gamma-irradiation and refrigerated storage on the quality of Shatang mandarin. Food Sci. Human Wellness 3(1): 9-15

Ke Zhang, Zhibin Li, Shaowen Zhu, Qunfang Weng, et al. 2014. 60Co-γ Irradiation affects the enzymatic antioxidant system of the citrus red mite *Panonychus citri* (Acari: Tetranychidae). Molecules 19(5):6382-6392

Khoury, H.J., E.J. da Silva, Jr, K. Mehta, V.S. de Barros, P.L. Guzzo and A.G. Parker 2014. Dosimetry of self-shielded low energy X-ray irradiator using alanine. 9th International Topical meeting on Industrial Radiation and Radioisotope Measurement Application, Valencia, Spain, 6-11 July 2014

Mansour, M and J. Al-Attar 2012. Effects of gamma irradiation on the grape vine moth, *Lobesia botrana*, eggs. Radiat. Phys. Chem. 81: 1776-1780.

Mansour, M and J. Al-Attar 2014. Effects of gamma irradiation on the grape vine moth, *Lobesia botrana*, mature larvae. Radiat. Phys. Chem. 97: 370-373.

Shao Y., L.L. Ren, Y.J. Liu, Y.J. Wang, Y. Jiao, Q.L. Wang, and G.P. Zhan. 2013. The primary results of the impact on the development and reproduction of Jack Beardsley Mealybug irradiated with Cobalt-60 gamma rays. Plant Quarantine, 27(6): 15-19. (Chinese with abstracts in English)

Wei Y.D., G. P. Zhan, Y. Cheng, Y.J. Wang, F. Yang, R.F. Zhang, and F.F. Kang. 2014. Effect of electron beam irradiation on the quality of apple 'Red Fuji'. Plant Quarantine, 28 (6): (in press) (Chinese with abstracts in English)

Zhan G.P., B.S. Li, M.X. Gao, B. Liu, Y.J. Wang, T. Liu, and L.L. Ren. 2014. Phytosanitary irradiation of peach fruit moth (Lepidoptera: Carposinidae) in Apple Fruits. Radiat. Phys. Chem. (in press).

Zhan G.P., L.L. Ren, S.R. Gong, T.X. Li, B.S. Li, and Y.J. Wang. 2014. A Comparison Study on the Radiation Tolerance of *Carposina sasakii* (Lepidoptera: Carposinidae) Pupae. Plant Quar. 28 (5): (in press) (Chinese with abstracts in English)

Zhan G.P., M.X. Gao, B.H. Ye, B.S. Li, T.X. Li, Y.J. Wang, B. Liu, and H.L. Qin. 2014. Irradiation effect on the eclosion rate of *Carposina sasakii* mature larvae. J. Nucl. Agric. Sci. 28(3): 453-458. (Chinese with abstracts in English)

Zhan G.P., Y. Li, T.X. Li, Y.J. Wang*, B.S. Li, and H.L. Qin. 2013. The primary investigation on the development of the eggs of Peach Fruit Moth after irradiated by cobalt-60γ-rays. Plant Quar. 27(1): 51-55. (Chinese with abstracts in English)

Zhu Fu-wei, Deng Yue-ye, Weng Qun-fang, et al. 2014. Effect of 60Co-γ irradiation combined with different temperature treatments on citrus red mite (*Panonychus citri* McGregor). J. Northwest Agric. For. Univ. (Nat. Sci. Ed.) 42(7):1-5

Zhu Fu-wei, Deng Yue-ye, Weng Qun-fang, Hu Mei-ying. 2012. Study on elimination effect of irradiation against different stages of citrus red mites (*Panonychus citri* Mcgregor). J. Northwest Agric. For. Univ. 40(5): 57-61. (in Chinese with English abstract)