



**USAID**  
FROM THE AMERICAN PEOPLE

**WATH** WEST AFRICA TRADE HUB  
CENTRE POUR LE COMMERCE  
EN AFRIQUE DE L'OUEST

# IRRADIATION QUARANTINE

*EXPORT DEVELOPMENT FEASIBILITY STUDY*

*WATH Technical Report No. 11*

**OCTOBER 2005**

This publication was produced for review by the United States Agency for International Development. It was prepared by Michelle Marcotte, Abt Associates Consultant, Dr. Ramatu M. Al-Hassan, University of Ghana at Legon, and Kofi Humado, West Africa Trade Hub.

# **IRRADIATION QUARANTINE**

***EXPORT DEVELOPMENT FEASIBILITY STUDY***

***WATH Technical Report No. 11***

## **DISCLAIMER**

The author's views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government.

# ACKNOWLEDGEMENTS

The authors appreciated excellent collaboration with other USAID programs, notably the West Africa Regional Program (WARP) and the USAID-Ghana project, Trade and Investment Program for a Competitive Export Economy (TIPCEE). We particularly appreciated information received from the food irradiation research team at the Ghana Atomic Energy Commission, Mr. Kofi Aseidu of Can and Kaa Ltd. and the Ghana Root Crop and Tubers Export Association, and Mr. Christian Foli of Farmapine. We have been fortunate to be able to build this report on the foundation started by Dr. Shawn Robertson, on loan to USAID from USDA APHIS, whose pest risk analysis formed the scientific foundation for the project.

And finally, the West Africa Trade Hub (WATH) not only funded this project but provided exceptionally strong staff support and encouragement. We especially appreciate the guidance and contributions of Andy Cook, Vanessa Adams, Kofi Humado, Leah Quin, and Catherine Kannenberg.

# TABLE OF CONTENTS

<b>LIST OF TABLES AND FIGURES .....</b>	<b>3</b>
<b>ACRONYMS AND ABBREVIATIONS.....</b>	<b>4</b>
<b>EXECUTIVE SUMMARY .....</b>	<b>5</b>
<b>1. BACKGROUND .....</b>	<b>7</b>
1.1 Exports to the U.S.: Why use irradiation? .....	8
1.2 Selection of candidates for irradiation.....	8
<b>2. FOOD RESEARCH IN WEST AFRICA .....</b>	<b>10</b>
2.1 Review of previous studies and suggestions for further research.....	10
2.2 Updating Ghanaian food research capability .....	11
<b>3. IRRADIATION: REGULATORY ISSUES .....</b>	<b>12</b>
3.1 Regulatory situation in Ghana .....	12
3.2 Revision of the Ghana Standard for irradiated food .....	12
3.3 Pertinent U.S. regulations and impact on feasibility .....	13
<b>4. AN IRRADIATION FACILITY FOR GHANA .....</b>	<b>16</b>
4.1 Options for locating an irradiation facility.....	16
4.2 The GAEC irradiation facility.....	17
4.3 Refurbishing the GAEC irradiator .....	18
4.4 Personnel training requirements.....	20
4.5 Training Ghanaians for irradiator operations.....	21
<b>5. COST-BENEFIT ANALYSIS OF IRRADIATION.....</b>	<b>23</b>
<b>6. AGRICULTURAL PRODUCTION AND EXPORT DEVELOPMENT .....</b>	<b>30</b>
6.1 Yam .....	30
6.2 Cocoyam .....	32
6.3 Chili pepper.....	32
6.4 Onions and shallots .....	33

6.5	Mango .....	34
6.6	Garden egg.....	35
6.7	Pineapple.....	35
6.8	Papaya .....	36
6.9	Vegetables.....	37
6.10	Smoked fish .....	39
<b>ANNEX 1. BASICS OF FOOD IRRADIATION &amp; EQUIPMENT SUPPLIERS ....</b>		<b>41</b>
<b>ANNEX 2. CONTACTS .....</b>		<b>43</b>
<b>REFERENCES .....</b>		<b>45</b>

# LIST OF TABLES AND FIGURES

Table 1.	Summary of mean treatment costs (U.S. dollars/tonne).....	23
Table 2.	Summary of estimates of investment returns.....	24
Table 3.	Estimates of mean treatment costs .....	25
Table 4.	Analysis of refurbishing GAEC facility with public sector investment .....	26
Table 5.	Analysis of refurbishing GAEC facility with private commercial investment....	27
Table 6.	Scenario of installing new equipment at GAEC.....	28
Table 7.	Investment analysis of purchasing new equipment.....	29
Figure 1.	Yam production in Ghana .....	30
Table 8.	Main actors in the Ghanaian yam market.....	31
Figure 2.	Yam exports from Ghana .....	32
Figure 3.	Exports of chili pepper from Ghana .....	33
Figure 4.	Seasonality of chili exports from Ghana in 2004.....	33
Figure 6.	Exports of eggplant from Ghana .....	35
Figure 7.	Exports of pineapple from Ghana .....	36
Figure 8.	Seasonality of pineapple exports from Ghana in 2004 .....	36
Figure 9.	Exports of papaya from Ghana.....	37
Figure 10.	Seasonality of papaya exports from Ghana in 2004.....	37
Figure 11.	Exports of vegetables from Ghana .....	38
Figure 12.	Seasonality of vegetable exports from Ghana.....	38
Figure 13.	Exports of processed fish from Ghana.....	39
Table 9.	Trends in exports of agricultural commodities from Ghana .....	40

# ACRONYMS AND ABBREVIATIONS

<b>APHIS</b>	Animal and Plant Health Inspection Service (of USDA)
<b>ASTM</b>	American Society of Testing Materials
<b>BINARI</b>	Biotechnology and Nuclear Agriculture Research Institute
<b>CODEX</b>	Codex Alimentarius Commission or CAC
<b>EU</b>	European Union
<b>FDA</b>	Food and Drug Administration (of the US Government)
<b>FOB</b>	free on board
<b>FY</b>	fiscal year
<b>GAEC</b>	Ghana Atomic Energy Commission
<b>ha</b>	hectare
<b>HACCP</b>	Hazard Assessment and Critical Control Points
<b>IAEA</b>	International Atomic Energy Association
<b>kCi</b>	1000 Curies (Ci)
<b>kg</b>	kilogram (1000 grams)
<b>kGy</b>	1000 Grays (Gy)
<b>lbs</b>	pounds (weight)
<b>MIS</b>	Market Information System (for Agricultural Products)
<b>MT</b>	metric tonnes (1,000 kg or 2,200 lbs)
<b>NGO</b>	non-governmental organization
<b>p.a.</b>	per annum
<b>PRA</b>	pest risk assessment
<b>RSO</b>	Radiation Safety Officer
<b>SOP</b>	standard operating procedure(s)
<b>SPS</b>	sanitary and phytosanitary (issues, regulations)
<b>SSA</b>	sub-Saharan Africa
<b>STTA</b>	short-term technical assistance
<b>U.S.</b>	United States of America
<b>USDA</b>	United States Department of Agriculture
<b>USDA ARS</b>	USDA Agriculture Research Service
<b>UV</b>	ultra-violet radiation
<b>WAIBL</b>	West African International Business Linkage Program (of USAID)
<b>WARP</b>	West African Regional Program of USAID
<b>WATH</b>	West Africa Trade Hub (of WARP/USAID)

# EXECUTIVE SUMMARY

West Africa exports very little fresh produce to the United States, in part because of stringent U.S. phytosanitary standards. Irradiation is likely to be approved by the United States Department of Agriculture as a blanket phytosanitary treatment for most pests, which makes this technology an appealing alternative treatment for many countries seeking to export fresh fruits and vegetables.

Ghana and the rest of West Africa produce many high-quality agricultural products, and irradiation may be the key to exporting those products to the United States. Irradiation is not a replacement for sound phytosanitary infrastructure, good field and packing practices, and proper pest control. However, irradiation complements these activities to insure pest-free fruits and vegetables.

Furthermore, protocols for the other two broad-spectrum pest treatments, methyl bromide and hot vapor, have not been established for pests present in West Africa. Designing new treatments using methyl bromide or hot vapor for these pests would require several years of extensive research, followed by years of bilateral negotiation.

The West Africa Trade Hub of USAID funded this project to explore the scientific, legal, commercial and institutional merits of using irradiation as a quarantine treatment to increase exports of Ghanaian and West African fruits and vegetables to the U.S.

As a summary of the project, this report:

1. Identifies likely candidates for irradiation quarantine treatment.
2. Provides an improved knowledge of U.S. quarantine regulatory requirements and the remaining hurdles to be accomplished in light of the regulatory situation in Ghana.
3. Suggests revisions of the Ghana Standard for Food Irradiation.
4. Discusses refurbishing current irradiation equipment in Ghana and the possible location of new irradiation equipment.
5. Assesses research and training needs.
6. Identifies agri-business contacts who may be eventual clients or owners of irradiators.
7. Drafts cost spreadsheets based on previously published work, adapted to the Ghanaian situation.
8. Includes data on current production of several agricultural commodities and export development activities in Ghana.
9. Informs the USDA Animal and Plant Health Inspection Service (APHIS), the International Atomic Energy Agency (IAEA) and members of the radiation processing and equipment supply industry about the project and its findings and solicits their assistance in moving Ghana and West Africa forward in food irradiation.
10. Summarizes the basics of food irradiation, and includes a list of irradiation equipment suppliers.

This report recommends next steps towards commercial irradiation quarantine treatment. The authors hope that the information presented here will help potential equipment buyers and sellers to determine costs and economic advantages of irradiation quarantine treatment. These recommended steps are listed below.

1. Request and obtain a pest risk assessment (PRA) for yams and determine if yams can be quarantine treated within the irradiation generic dose regulation.



2. Revise the Ghanaian Standard for Irradiated Foods, harmonizing it with other world standards in this field and with U.S. regulation, and making certain it contains the elements needed for the Framework Equivalency Agreement and Compliance Agreements.
3. Obtain engineering assessment(s) to determine if the Ghana Atomic Energy Commission (GAEC) irradiator can be sufficiently refurbished, or whether a new facility is necessary.
4. Draft Framework Equivalency Agreement with U.S. and obtain agreement with the U.S. Government.
5. Request that International Atomic Energy Agency (IAEA) or USDA provide American research consultant(s) to assess quarantine and food quality research capability, operations and facilities and formulate a revised work plan.
6. Obtain irradiator costs from irradiation equipment suppliers in the context of likely Ghanaian export volumes and conditions, and revise the cost spreadsheets to assist the investment decision.
7. Decide whether to refurbish the GAEC irradiator.
8. Work bilaterally with GAEC and USDA/APHIS and American importers to arrange shipping trials of irradiated yams, papaya, vegetables and mango, evaluate the results and draft best practices guidelines.
9. Train and qualify sufficient personnel to operate a food irradiator.
10. Draft and obtain approval for a Compliance Agreement, required for each commodity.
11. Make a decision about irradiator location and ownership.

With strong collaboration and appropriate funding, it should be possible to complete Items 1 - 6 by the end of 2006. Furthermore, it may be possible to accomplish some of the food research and shipping trials identified in Item 8 in this same timeframe, although completion of the shipping trials might have to wait until the irradiator is refurbished.

As indicated in Item 9, much of the training should be accomplished before the irradiator is refurbished. This training will be an ongoing task for Ghana, initially through attendance at courses in Canada or elsewhere, and eventually organized by the GAEC. Newly trained persons would work with the equipment supplier during the construction and commissioning phases of the irradiator.

If an engineering assessment indicates that the GAEC irradiator can be refurbished (Item 3) and if a policy decision to do so is made (Item 7)--given available funding--refurbishment could be accomplished within 12 - 16 months of the availability of funding. This project does not need to wait for Items 1 - 6 to be accomplished.

Item 9 can begin when the irradiator is purchased or refurbished to ensure it is almost done when the irradiator is being commissioned. Once the work is completed for USDA Facility Certification and the Compliance Agreement, quarantine treatments could begin soon after the new irradiator opens. A delay in starting Item 9 will increase irradiator costs, with no revenues to offset them.

If Ghanaian commercial companies have interest and financial backing, Items 10 and 11 could proceed in the next two years on a separate track, but the other regulatory, research and training goals outlined will still need to be addressed.

By virtue of its long history in food irradiation research, and considering its political stability, improving economic picture, and current export success, Ghana is well positioned to be the West African leader in the use of irradiation as a quarantine treatment. Since the U.S. has recently made considerable advances in its regulations for the approval of irradiation as a quarantine treatment, it truly seems that this project has a good chance of eventual success.

# 1. BACKGROUND

West Africa exports very little fresh produce to the United States, in part because of stringent U.S. phytosanitary standards. As scientists and policy makers learn more about the complex of pests and diseases present in many exporting countries, phytosanitary standards will become more stringent, making it even more difficult to trade in many fresh commodities. It takes researchers time and effort to test phytosanitary treatments against new pests and to get those treatments approved by importing countries like the United States. Irradiation is likely to be approved by the United States Department of Agriculture as a blanket phytosanitary treatment for most pests, which makes this technology an appealing alternative treatment for many countries seeking to export fresh fruits and vegetables. Because this treatment is relatively new, many questions need to be answered before it can be employed for successful and safe trade.

Irradiation, as a phytosanitary treatment, is not a replacement for sound phytosanitary infrastructure, good field and packing practices, and proper pest control. However, irradiation complements these activities to insure pest-free fruits and vegetables. Ghana and the rest of West Africa produce many high-quality agricultural products, and irradiation may be the key to exporting those products to the United States.

This report examines the feasibility of irradiation as a quarantine treatment for West African exports, especially to the United States. The project was designed to assess current agricultural production, storage, market logistics and the economics of processing, including costs and profitability, along with future projections using irradiation. At the same time, the project assessed the regulatory requirements of the U.S., the current status of the irradiation facility in Ghana, the laws and standards for irradiation in Ghana, and the cost effectiveness of using irradiation compared to other phytosanitary treatments. This ambitious project tasked two consultants, each working about 24 days.

This report summarizes the work of the project and:

- Identifies likely candidates for irradiation quarantine treatment.
- Provides an improved knowledge of U.S. quarantine regulatory requirements and the remaining hurdles to be accomplished in light of the regulatory situation in Ghana.
- Suggests revisions of the Ghana Standard for Food Irradiation.
- Discusses refurbishing current irradiation equipment in Ghana and the possible location of new irradiation equipment.
- Assesses research and training needs.
- Identifies agri-business contacts who may be eventual clients or owners of irradiators.
- Drafts cost spreadsheets based on previously published work, adapted to the Ghanaian situation.
- Includes data on current production of several agricultural commodities and export development activities in Ghana.
- Informs the USDA Animal and Plant Health Inspection Service (APHIS), the International Atomic Energy Agency (IAEA) and members of the radiation processing and equipment supply industry about the project and its findings, and solicits their assistance in moving Ghana and West Africa forward in food irradiation.
- Summarizes the basics of food irradiation, and includes a list of irradiation equipment suppliers.

It was difficult to reliably determine costs of irradiation quarantine treatment here in Ghana. Spreadsheets based on previously published work, adapted to the Ghanaian situation, are included in this report. Our initial results show irradiation costs were comparable to or higher than methyl bromide fumigation for yams based on current yam methyl bromide fumigation costs. On the other hand, irradiation might reduce the incidence of yam spoilage on arrival, improving the cost-benefit scenario. Furthermore, our cost-benefit analysis was done on the maximum dose of 1 kGy, and in fact the dose will likely be between 0.4 kGy and 1 kGy, improving the cost analysis somewhat.

## 1.1 Exports to the U.S.: Why use irradiation?

With the exception of yam, current U.S. import volumes of Ghanaian fruits and vegetables are miniscule compared to what is currently exported to the EU. (For quantities, refer to tables in Section 6 on agriculture production and export development.) In large part, the reason is that the EU quarantine requirements are virtually non-existent compared to those in the U.S. The pest complex in Ghana means that without a reliable and accepted broad spectrum quarantine treatment, Ghanaian fruits and vegetables will not be allowed to enter the U.S.

There are three such broad spectrum treatments allowed by the United States Department of Agriculture (USDA) and suitable for many fruits and vegetables: methyl bromide fumigation, hot water or vapor treatment, and irradiation.

Methyl bromide is still allowed for quarantine use under the Montreal Protocol on Ozone Depleting Substances. Ghana and the United States are parties to this Protocol with the purpose of eliminating the use of ozone depleting substances, including methyl bromide. In general, where possible, parties to the Protocol are avoiding the establishment of new methyl bromide treatments. As with irradiation, proposing methyl bromide treatment for Ghanaian fruits and vegetables would require the establishment of new treatment protocols, new equipment purchases, etc., and require that quarantine uses of methyl bromide would not be eliminated under the Montreal Protocol.

The larger problem with methyl bromide is that no treatments have been established for the pests present in West Africa. Designing those treatments would require years of research, to the Probit 9 Security levels required by the USDA, followed by years of bilateral negotiations. The research would have to address each of the many pests present in Ghana.

Hot water and hot vapor treatments are used in some regions for some of the fruits under consideration in Ghana. But this treatment can cause more quality losses than irradiation. Similar to irradiation and methyl bromide, proposing hot water as a treatment requires the same work in establishing protocols, equipment purchases, etc. Again, with no treatment established for West African pests, there would be years of research and bilateral negotiations required.

Irradiation is a reliable broad spectrum quarantine treatment that maintains good quality in treated fruits and vegetables. Establishing its use as a quarantine treatment will require completion of multiple regulatory, policy and investment hurdles, but these will be considerably less cumbersome than the requirements for other quarantine technologies. The main reason for this is that the USDA published a Proposed Rule in June 2005, which will allow the use of irradiation as a quarantine treatment on any commodity for any arthropod pest, except Lepidoptera adults and pupae which can be removed in packhouse procedures.

Therefore, a realistic evaluation of the three technologies in the context of Ghanaian pests suggests that unless irradiation technology is adopted, Ghana may never be able to export high volumes of fruits and vegetables to the United States.

## 1.2 Selection of candidates for irradiation

Likely candidates for irradiation were selected based on three criteria:

- The product is grown or produced in Ghana or neighboring West African countries.
- The product is infested with pests that limit its export to the U.S. or has other limits to exporting, such as sprouting or short shelf life.
- Irradiation will resolve the pest, sprouting or shelf-life problem and will not compromise quality.

Note that this assessment was made in spite of gaps in the available research on quality effects at the maximum dose for quarantine treatment (1 kGy<sup>1</sup>). Obtaining this information has been identified as a research need.

Based on the criteria above, the best candidates for quarantine treatments are:

- Yam
- Mango
- Papaya
- Eggplant (including aubergine and the small white eggplant known as garden egg)
- Roots and tubers such as sweet potato, ginger, shallots, onions
- Chili peppers, fresh and dry
- Herbs and spices, herbal teas

Commodities that can be irradiated but for which we know less about pest problems, logistics of treatment, or export issues are:

- Cocoa beans
- Frozen shrimp (for control of food-borne bacteria)

Other commodities with a requirement for irradiation include:

- Pineapple. Although a quarantine treatment is not required by the U.S., irradiation, in combination with good handling and shipping practices, can be used to control cosmopolitan or hitchhiking pests, and decrease incidence of fungal spoilage. Ghanaian growers have considerable interest in expanding pineapple exports to the U.S. and have recently made contact with U.S. import brokers. The presence of pests in pineapple can result in costly fumigation upon inspection in the U.S., and fungal spoilage can be a costly problem and a deterrent to exports.
- Basketry and handicraft items; for hitchhiker pests to avoid fumigation in the U.S.
- Okra and other vegetables have pest problems but not enough is known about tolerance of these vegetables to irradiation. More research is needed.
- Citrus; not enough is known about pests and irradiation tolerance.

Scientists at the Ghana Atomic Energy Commission (GAEC) have also identified the horticultural products listed above as good prospects for domestic markets. For domestic markets, irradiation would be used for phytosanitary reasons, delayed ripening, or inhibition of sprouting. Delaying ripening and sprouting is essential for Ghanaian fresh produce exports, most of which are presently sea freighted. Previous customers of the GAEC also suggest some level of awareness and interest in irradiation processing by local agribusinesses. Products that have been irradiated include intravenous infusion sets, spices, yam, cocoyam, pineapple, smoked fish and herbal tea.

---

<sup>1</sup> The SI unit of the absorbed dose of ionizing radiation. 1 gray (Gy)=1 joule per kilogram.

## 2. FOOD RESEARCH IN WEST AFRICA

### 2.1 Review of previous studies and suggestions for further research

- Review of initial and basic irradiation research on several common foods in West Africa.
- Improve research reporting and documentation.
- Conduct food quality research at 1 kGy for export commodities.
- Conduct and evaluate shipping trials.
- Use results of quality research and shipping trials to prepare Guidelines for Best Practices and Compliance Agreement with the U.S.

The IAEA published a study of the impact of food irradiation on preventing losses in Africa in 2002, summarizing the proceedings of the final research coordination meeting. Reports were published from several West African countries: Ghana, Senegal, Cote d'Ivoire and Nigeria as well as a summary of research in Zambia (IAEA, May 2002). The future research interests of the GAEC were reported in the IAEA study, and shared with the authors of this report.

The Ghanaians reported that irradiation of yam after harvest diminished losses from sprouting and rotting. Post-harvest losses of yam were reported to be between 20–60%, a terrible waste to any country, let alone one with occasional food shortages. Researchers from the GAEC demonstrated extensive knowledge of yam storage, handling, and transportation and suggested improvements. Their current knowledge and expertise deserves to be better known, and should be disseminated through publications worldwide. Their report includes an economic analysis of the irradiation of yam and improved storage methods. While the GAEC report is quite positive, the authors of the present report note that export shipments of yam take place year-round. Since the irradiation quarantine treatment occurs just prior to shipping, the results of the GAEC study on freshly harvested yams may not be entirely pertinent.

The GAEC study on maize emphasized proper handling of irradiated foods, and the need for shipping trials under appropriate commercial conditions of transportation.

Irradiation of cocoa up to 6 kGy did not adversely affect the quality parameters of products processed from it, such as cocoa butter. This study, a collaboration of University of Ghana and the Cocoa Research Institute, is one of very few worldwide that shows an analysis of cocoa composition after irradiation. It would be helpful if this information was more widely known and if the Cocoa Research Institute of Ghana (CRIG) could assist GAEC to arrange trial shipments for American research on the organoleptic properties of irradiated cocoa beans.

In the future, semi-commercial research on the key export commodities is needed (defined as large scale, incorporating commercial transportation and marketing logistics, with realistic storage and handling processes). Even before shipping trials are done, however, more food quality research on the key export commodities is needed to determine if they can withstand the maximum quarantine treatment dose of 1 kGy (although depending on irradiator design the maximum dose may not be as high as 1kGy.) This work has been done (but not reported) with mango and eggplant, but not the other commodities. This lack of documentation is a problem; we have learned that some irradiated yam shipping trials have occurred, but there is no documentation on those trials. For this work to be useful, it must be documented.

Shipping trials under commercial conditions of transport and handling are required. Shipping trials will inform the Ghanaian horticultural export industry whether irradiated fruits and vegetables arrive in the U.S. in good condition and if quality losses occur throughout the marketing channel. Shipping trials will allow government and industry to evaluate and improve methods (such as by using irradiation and cold storage for example). Then, guidelines for best practices and standards can be developed to ensure that irradiated produce from Ghana arrives at the export destination and its quality is high. The documented results of

shipping trials will be needed to form part of the Compliance Agreement with the USDA. Furthermore, several of the persons interviewed for this report would prefer to use less expensive sea freight for shipments to the U.S. Irradiation results in shelf-life extension under some circumstances and with some fruits and vegetables, but shelf-life quality research at the maximum dose is necessary, followed by shipping trials to determine if sea freight is feasible.

A collaboration of Senegalese and French researchers reported the economic feasibility of using irradiation for domestically consumed common foods. They asserted that a privately owned irradiation company would be profitable in Senegal if there was a total product throughput of 22,000 – 77,000 tonnes, at the low doses suggested. However, they cautioned that consumer and market acceptance studies had not been done.

Côte d'Ivoire conducted economic analyses of yam irradiation and storage, similar to the work in Ghana, and with the assistance of the GAEC. This underscores the importance of refurbishing the GAEC irradiator to enable it to serve the West Africa region.

## 2.2 Updating Ghanaian food research capability

- Although Ghana has an experienced and accomplished research team, it no longer has an adequate irradiator with which to do the research required.
- IAEA and/or USDA might be approached to send qualified scientists for a peer review of lab operations and equipment and to refocus the research program. The goal should be the ability to do modern, well-documented and publishable research on par with other food irradiation research scientists and credible to importing country regulators.

The GAEC formed the Biotechnology and Nuclear Agriculture Research Institute (BINARI) in 1993 from the former National Nuclear Research Institute. In the early decades of food irradiation, Ghana was a leader in basic research on the effects of irradiation on African foods.

Ghanaian research was once published in documents of the International Consultative Group on Food Irradiation (ICGFI) under the aegis of IAEA, which provided the best publication venue in this field from the 1970's and to the early 1990's. However, for some years now, irradiation research has been published in peer-reviewed journals. Such publications are critical if importing countries' industries and regulators are to have confidence in the quality of Ghanaian research. Since the ICGFI disbanded, Ghanaian research has not been disseminated broadly.

However, a food irradiation research program needs access to a fully functioning irradiator, which has been lacking for many years now. The food research program needs a revitalized irradiator to do modern research suitable for publication in peer-reviewed journals and in food and agriculture industry publications, and for acceptance by importing country regulators. The authors of this report have respected Ghanaian food irradiation research for years, but note that research done to modern standards is lacking, especially on quality of food irradiated at 1 kGy, in shipping trials and the drafting of best irradiation practice guidelines, and on consumer and market acceptance. Also, although recent proposed regulation in the U.S. reduces the urgency for some entomology research agendas, additional research may help to understand the effect of irradiation at quarantine doses on pests and diseases present in Ghanaian produce.

Given the research needs and the reality of good human resources in GAEC, the labs may need to be modernized and the work plan refocused on basic research and high quality semi-commercial work of use and interest to Ghana's food industry, and acceptable to importing country regulators and consumers. The IAEA or the USDA Agriculture Research Service (ARS) may be able to assist with assessing the needs of the research labs and refocusing the work plan to prioritize modern and useful food research. Recently, the IAEA sent a very experienced USDA ARS research entomologist, Dr. Peter Follett (Hilo, Hawaii), to Bangladesh to assess the needs of their labs and to make recommendations on their work plan so that they could update their quarantine research (Follett, 2005). USDA ARS has other suitable experts, such as entomologist Dr. Guy Hallman in Weslaco, Texas, and Dr. Marisa Wall, a research scientist with experience in irradiated food quality research, also at USDA ARS in Hilo, Hawaii.

## 3. IRRADIATION: REGULATORY ISSUES

### 3.1 Regulatory situation in Ghana

- Ghana has nuclear safety and regulatory authorities to satisfy international regulators.
- Ghana's Standard for Food Irradiation has to be carefully revised to satisfy domestic and international regulatory needs and to be equivalent to other world standards.
- A Framework Equivalency Agreement with the U.S. is necessary, and could be initiated after the Standard is revised.

Ghana's history of using nuclear energy for peaceful purposes goes back to 1961. Currently the country has a large nuclear research establishment, the Ghana Atomic Energy Commission (GAEC) located near Accra. The GAEC includes at least two institutes relevant to this report: the Biotechnology and Nuclear Agriculture Research Institute (BINARI), whose work is discussed in a later chapter of this report, and the Radiation Protection Institute, which provides regulatory control programs and services for licensing irradiation equipment under the authority of the Atomic Energy Act 588 of 2002. This legislation and institute will enable a Ghanaian irradiator to meet the requirements of other governments that seek assurance that the facility will be licensed and controlled by appropriate and competent national authorities.

Additionally, Ghana has a Standard for Irradiated Food (GS 210:1998, under revision), detailing process control procedures for food irradiation and irradiator requirements. When this Standard—similar to U.S. 21CFR Part 179—is revised, it will provide a reliable component for the Framework Equivalency Agreement and Compliance Agreements with USDA that will eventually be required. Suggestions for revision of the Standard are included in this report.

As discussed in more detail in Section 3.3 on the U.S. regulatory situation, Ghana needs to draft a Framework Equivalency Agreement and obtain USDA approval. Then, a Compliance Agreement must be prepared bilaterally for each product to be irradiated as a quarantine treatment. Ghana should have the supporting Standards and other regulatory mechanisms that may be required for these agreements.

### 3.2 Revision of the Ghana Standard for irradiated food

- Revise the Ghana Standard to be consistent with that of American Society of Testing Materials (ASTM) and U.S. regulations.
- Revise the scope of the Standard to be more accurate and to ensure it can be used as a basis of the Framework Equivalency Agreement with the U.S.
- Several suggestions for revisions of treatment doses are made, of which the most important is to allow the U.S. minimum dose for yam as a quarantine treatment.

The current Ghana Standard for food irradiation is under revision by a national committee. During the revision, the committee should consider the following issues identified by the authors of this report.

Revisions to the Standard should be harmonized with the ASTM standards in the E10:01 series. ASTM standards are developed through a consensus committee process that is intended to ensure world-wide agreement and compliance. The radiation processing industry uses ASTM Standards to ensure the safe and effective use of irradiation.

The scope of the current Standard does not accurately describe its purpose. For the USDA to support an agreement, the Ghanaian committee should specify that the purpose of the Standard is to obtain approval for the irradiation of foods and quarantine treatment, if the foods are irradiated according to the Standard, using a nationally licensed irradiator. To ensure that the Standard meets the requirements for a Framework Equivalency Agreement between Ghana and the U.S., the Ghanaian Standard should not limit its scope to foods irradiated in Ghana. Instead it should clearly specify that foods irradiated in accordance with Ghanaian

or other national standards (such as those of the U.S.) are acceptable. Ghana may wish to articulate that irradiating food according to CODEX standards, for example, is sufficient.

The revision committee may also want to refer to the U.S. Food and Drug Administration's basic regulation on food irradiation—21 CFR Part 179 (Part 579 for pet food)—to see how to harmonize the Standard with U.S. regulations. The dose limits set by the U.S., as well as the sources and power levels allowed, are different from those allowed in Ghana. The USDA also has several regulations for food irradiation, found in 7CFR Part 301 and Part 305. The USDA regulations pertain to treatment of fruits and vegetables for quarantine.

The maximum dose of an overall average of 10 kGy in Ghana is consistent with the old CODEX Standard, but in actual use is unnecessarily complicated and not always sufficient for decontamination of herbs and spices. By comparison, Canada has a maximum dose of 15 kGy for herbs and spices (which is not always sufficient either), whereas the maximum dose for herbs and spices is 30 kGy in the U.S. Ghana may also find useful information in the various Codes of Good Irradiation Practice published by the former International Consultative Group on Food Irradiation, if they are not outdated for the Ghanaian situation.

Additionally, Annex B of the Standard lists several maximum doses that must be revised to allow irradiation in Ghana. For example, Class 1 lists a maximum dose of 0.2 kGy (200 Gy) for bulbs, roots and tubers, including yams. However, the generic dose for quarantine treatment for these foods to the U.S. is a minimum dose of 0.4 kGy (400 Gy). As a result, without revision, yams cannot be irradiated for export to the U.S.

The dose for fresh and frozen fish and seafood should be revised after a review of world-wide research literature and in consideration of the pathogens present in fish and seafood in Ghana. As discussed below, the maximum doses in the current standard may be too low. Similarly the maximum doses for shelf life extension for fresh and frozen poultry and meats may be too low. As previously mentioned, the maximum dose for herbs and spices is too low based on extensive commercial experience in Canada and the United States. The 30 kGy dose used in the U.S. has proven effective and safe. The dose for decontamination of animal and pet feeds in the U.S. is 50 kGy, significantly higher than the Ghanaian Standard. The high dose is required because pet foods are dry commodities and occasionally have high contamination levels. In Class 7, a maximum dose of 3 kGy for mold control for dried fish seems insufficient; in commercial practice, a typical minimum dose for mold control is 3 kGy. The Standard does not include a Class for shelf-stable foods, but adding approval for this category should be considered in the context of recent research and commercial marketing of shelf-stable irradiated food in South Africa.

### 3.3 Pertinent U.S. regulations and impact on feasibility

- The U.S. government has proposed a 400 Gy (0.4k Gy) generic quarantine treatment dose for all arthropod pests except *Lepidoptera* adults and pupae, which can be removed in packhouse procedures. This proposed rule is not yet final.
- The generic dose does not eliminate the need for pest risk assessment.
- A pest risk assessment for yam should be a priority.
- Ghana needs a Framework Equivalency Agreement with the U.S. which can be done once the Ghana Standard is revised.
- Requirements for USDA/APHIS facility certification and Compliance Agreement are summarized.

**Treatment dose.** From a regulatory perspective, the timing for Ghana to be moving towards commercial use of irradiation as a quarantine treatment is excellent. In June 2005, the U.S. government published a draft regulation, called a Proposed Rule, on the use of irradiation to treat fruits and vegetables (Federal Register, June 10, 2005 pp 33857 – 33873). This regulation proposes significant improvements in how the U.S. government will allow irradiation for quarantine treatment. It is important to note, however, that as a Proposed Rule, it might change and, in any case, will not be final until at least mid-2006, possibly later.

Of greatest significance for Ghana, the regulation establishes a 400 Gy generic dose for the treatment of any imported fruit and vegetable against all arthropod pests, other than adults and pupae of order *Lepidoptera*. It also establishes lower doses for the treatment of some pests. These are useful if the product to be imported



to the U.S. is known to be infested with arthropod pests only. The Rule does not provide a dose for mites, molluscs, nematodes and plant pathogens, since the USDA does not have sufficient information about the response of those pests to irradiation.

Thus, completing the pest risk assessment (PRA) is so important because it establishes the pest lists from which we can determine if only arthropod pests are included. Dr. Shawn Robertson (USDA/APHIS scientist on loan to USAID West Africa Regional Program) and Ghanaian pest risk assessors from the Plant Quarantine and Regulatory Service have recently submitted several PRAs for West African products. The pests listed for mango, eggplant, papaya and okra include several species of order *Lepidoptera*, but no mites, molluscs or plant diseases. This is good news, because although adults and pupae of *Lepidoptera* are not allowed, they can be eliminated through good packhouse procedures.

In spite of the favorable developments in the regulatory picture, a problem with irradiating yams remains. There is no PRA for yams that would establish which pests are a problem, and to know if any of them are nematodes, mites or plant diseases of quarantine significance. Theoretically, since methyl bromide treatment is being used, a PRA should have been done. However, several years ago, USDA/APHIS decided to allow methyl bromide treatment without a PRA. Dr. Robertson has recently developed an initial pest list for yams that includes some nematodes, and we are trying to determine if these are of quarantine significance (Robertson to Marcotte, personal communication, 2005). The presence of at least some nematodes emphasizes the need for a PRA to ensure that there are no nematodes of quarantine significance.

So, how can we get a PRA for yams? The government of Ghana could make the request to USDA/APHIS, or American importers of yams could initiate a request via USAID. Ideally, all of these interested parties should request a PRA for yams.

As noted above, the proposed regulation is not yet final and cannot be used by industry until then. The government of Ghana should urge the U.S. government to finalize the regulation specifying a generic dose of 400 Gy, which would facilitate Ghanaian produce exports to the U.S. This could be accomplished through diplomatic channels or by writing the regulatory contact (Dr. Inder Paul Ghad, address in contact list).

**Framework Equivalency Agreement – an unknown.** Ghana will need to draft a Framework Equivalency Agreement and obtain American approval for it. USDA's requirements for the Framework Equivalency Agreement are poorly understood even by USDA. It has been described as an agreement in which the country wishing to export to the U.S. has appropriate and sufficient regulations that would allow it to also *import* irradiated food from the U.S., in the event that would happen (however unlikely). At this point only the government of Mexico has managed to achieve a Framework Equivalency Agreement, but it might form the basis for a similar document in Ghana.

Recently, a USDA official described the Framework Equivalency Agreement as a work plan detailing what is expected of each party, outlining the fundamental requirements that will allow bilateral movement of irradiated product. The document should include treatment objectives and describe inspection and monitoring activities. Ghanaian Standards have to clearly indicate the legal authority to use irradiation as a phytosanitary method. If the USDA agrees that these elements are the only ones necessary for the Framework Equivalency Agreement, it could be in place before a facility opens. It is recommended that the Framework Equivalency Agreement be complete before the facility opens to avoid costly and lengthy delays.

If, however, the USDA insists that the Framework Equivalency Agreement also include other elements that are more appropriate to the Compliance Agreement (facility approval, compliance procedures, and operational methods), then the Framework Equivalency Agreement cannot be completed until the facility is being built, with the risk that it will not be completed prior to its opening.

**Facility certification.** USDA requires that irradiation facilities used for quarantine treatments be certified by USDA. They describe the general requirements in the USDA/APHIS Plant Protection and Quarantine Treatment Manual (Chapter 6). Chapter 3 of the same document details U.S. policy, lists the pertinent regulations and explains how inspectors make facility certification and inspection decisions. This chapter contributes important information to anyone drafting a Compliance Agreement and request for certification.

*These chapters may be the two most important references cited in this report.* The newest version of the APHIS Treatment Manual is available for downloading from their website at [www.aphis.usda.gov](http://www.aphis.usda.gov).

Approved facilities must be able to demonstrate that their equipment and personnel can deliver the minimum dose safely, accurately, and consistently to all components of the treated commodity over the range of conditions expected. It is not as detailed as persons unfamiliar with USDA requirements might like, but it does outline the following key points. The facility must:

- be licensed by all relevant local and national authorities;
- be capable of delivering the required dose;
- be constructed to ensure physical separation of untreated and treated commodities;
- have documented training of personnel;
- have documented standard operating procedures (SOPs) defining the processing, handling and safeguarding of regulated agricultural commodities (these must be approved and take the form of a Compliance Agreement).

Each of these five requirements represents a major undertaking. The ultimate goal is to have a USDA-certified facility and a Compliance Agreement with the U.S.

Licensing the facility is usually a multi-step procedure and is done both during the sale of the equipment and prior to the arrangements to ship cobalt-60, if it is to be a radioisotope facility. Depending on local or national regulations, final licensing inspections are often done after the facility is commissioned. Equipment suppliers can often help with the paperwork and documentation required for licensing, but the facility owners and managers will also have a lot of regulations to contend with in the licensing phase.

Capability to deliver the required dose means that the facility has to be correctly designed and have sufficient yet—in the case of quarantine treatments—not excessive cobalt-60. Working with an equipment supplier or assistants who can ensure the design will be suitable for the intended purpose is critical.

USDA requires that the facility be constructed in such a way that ensures biological security of the treated commodity. Warehouse and product handling procedures must prevent inadvertent or fraudulent mixing of treated with untreated boxes. This requires both physical separation and documented procedures for product handling. In addition, USDA wants assurance that pests capable of movement cannot move from the untreated product to infest the treated product. This requires screening and pest-proof containers.

As discussed in Section 4.4 on personnel training requirements, the facility must have properly credentialed and trained employees, and individual employee training should be documented. The USDA seeks to ensure that irradiator managers and workers will have the capability, understanding, and authority to carry out quarantine treatments as specified by the SOPs. Training sufficient persons will take time and, in the case of Radiation Safety Officers and irradiator operators, this training must occur before the irradiator is built.

The irradiation facility is required to have well-documented SOPs detailing the processing, handling and safeguarding of the regulated agricultural commodity. These SOPs will form part of the Compliance Agreement with the USDA and will be part of inspection procedures. The facility must identify an individual who has the authority to ensure compliance with SOPs and is physically located at the facility.

To certify an irradiation facility, a proposal addressing each of the five points outlined above—including identification of the operator, owner and the individual responsible for the compliance agreement, a plan of the facility and its processes, procedures and product flow—is sent to USDA with a request for approval (USDA APHIS PPQ, address in contact list).

When all documents have been approved, a USDA inspector will visit the facility, perhaps accompanied by the National Plant Quarantine officials. After certification, USDA may also make spot checks. If USDA approves of the facility, it will issue a Certificate of Approval, valid for one year unless revoked. Annual recertification is required.

## 4. AN IRRADIATION FACILITY FOR GHANA

### 4.1 Options for locating an irradiation facility

- USDA regulations do not require the irradiator location to be immediately adjacent to the port or airport, but strict adherence to SOPs and approved insect-proof packaging are required.
- There are several possible facility locations; market logistics and/or government policy will determine which is most suitable.

Several options for the location of an irradiation facility have been suggested by Ghanaians interviewed for this study and by the authors themselves. Ultimately, however, that decision should be made by the persons investing in an irradiator, taking into consideration how the irradiator will fit into food marketing logistics, regulatory requirements, etc.

A review of USDA APHIS regulations and a recent email clarifying the issue have indicated that with proper SOPs, strict conformance to the procedures, and the use of insect-proof packaging, the irradiator could be located nearby, but not necessarily at, the point of embarkation. This offers the flexibility to site the irradiator in locations that are suitable for the commercial logistics of packing and transportation.

Possible site locations include: (a) the Ghana Atomic Energy Commission campus; (b) a perishable packing shed at the airport; (c) a perishable shipping and inspection shed at the sea port; (d) on the land where the National Yam Packhouse intends to expand; (e) as part of the Farmapine packing operation, when it expands into papaya and sweet potato, and (f) other possible locations.

- a) The Ghana Atomic Energy Commission (GAEC) campus is such a good possibility that this report describes the site and discusses its refurbishment in more detail in a separate section.
- b) There is currently a perishable packing shed at the airport, but we have not seen it. The Ministry of Agriculture's Plant Quarantine and Regulatory Service intends to build a new facility at the airport that will be better for cold maintenance, for conducting inspections, and for handling a wide variety of perishable commodities. Locating an irradiator at the airport might not be possible because land availability is limited by its urban location and by the rapid growth and development of Accra. However, there is still land available in Accra near the airport; with good operating procedures and strict adherence, the products could be irradiated, then trucked to the airport. It will be important for this new facility to meet the needs of the export companies; these companies are concerned that a facility built and operated by government might not be satisfactory. However, it is possible that such a facility could work well logistically with an irradiation facility associated with it, and close to the airport. Cold-chain maintenance, as planned for this facility, is very important for most fruits and vegetables, although less critical for yams, which are cold sensitive below 15°F. In summary, this location has much to offer. Currently, the Ghanaian government Yam Export Standard of 2004 requires that all yams for export to North America be shipped by air freight (Ministry of Trade and Industry, July 6, 2004). Through conformance to this Standard and the use of the National Yam Packhouse, both the Ghanaian and U.S. governments have successfully deterred the previous problem of criminal drug exportation with the yams. Given the potential for drug shipments with yams to the U.S., and the serious impact they would have on Ghana, it seems quite unlikely that yams will be sea-freighted to the U.S.
- c) Currently the Plant Quarantine and Regulatory Services of the Ministry of Food and Agriculture operates a perishable shipping and inspection shed (Shed 9) at the sea port. The sea port is a large, bustling, rather challenging place to do business and inspections, but in spite of these observations, there is a lot of business conducted there. Currently, all the export companies we talked to used sea

freight for shipments of yams and other perishable products to European Union countries. Jean-Michel Voisard, Export Business Development Director of the USAID Trade and Investment Program for a Competitive Export Economy (TIPCEE), prefers that exporters develop markets based on sea freight shipments. He pointed out that air freight shipments contribute 40-50% of total costs while sea freight contributes 12-20% of total costs. On the other hand, Christian Foli, Managing Director of Farmapine, noted that sea freight to the United States takes 17 to 20 days (depending on which Ghanaian port is used), whereas it takes just 12 days to Mediterranean countries and 14 days to Belgium or the UK. This is a significant time difference for perishable products, especially when the additional marketing days would be needed for produce to move from the U.S. port to retail destinations in the country.

- d) The National Yam Packhouse is currently located near the outskirts of the port, a good business location close enough to the port but removed from its more challenging problems. The Yam Packhouse is a very busy operation, and its current site does not have enough land for an irradiation facility. The Ghana Root Crop and Tubers Exporters Association, which owns and operates the packhouse, hopes to expand to a new facility, three times larger, to handle the growing yam export business. This new packhouse could be located on land expansive enough to include an irradiator, but the yam exporters have also indicated some interest in placing their facility near the GAEC, if that is where a semi-commercial irradiator will be located. With the establishment of the yam packhouse, this association has shown that companies working together can revolutionize and expand an export system through the establishment and adherence to standard procedures.
- e) Farmapine is a company formed to pack and market pineapple and other fruits and vegetables by four grower cooperatives. Their packhouse is located on a large campus near the growing region, about 1.5 hours from Accra. The packhouse is EU-certified, as such, they are accustomed to working with standard procedures. Farmapine, well-established in the pineapple export business, is using non-irradiation procedures to remove pests. However, they have interest in irradiation procedures as they plan to begin exporting papaya and sweet potato—both good candidates for irradiation.
- f) Other locations. Depending on the export strategy chosen by Ghana, other companies and options may present themselves, especially if the GAEC irradiator is refurbished and becomes capable of researching and developing newer applications.

## 4.2 The GAEC irradiation facility

- The current status of the Ghana Atomic Energy Commission (GAEC) irradiator is described.

The GAEC has an irradiation facility on its large campus in the suburbs of Accra, a fairly lengthy drive from the airport and even further from the seaport.

Following a successful irradiation research program, the International Atomic Energy Agency installed the equipment in Ghana with a Hungarian irradiator donated in 1994. Although rated for a capacity of 500,000 Curies, it had an initial source load of 50,000 Curies. Funds to replenish the source, now at a strength of only 10,000 Curies, have been lacking. So, although the facility was initially doing some commercial irradiation, its dose delivery is now 0.2 Gy/minute, making it virtually impossible for commercial irradiation and probably even difficult to use for food irradiation research.

The facility is a cobalt-60 isotope irradiator, wet source storage system (meaning the cobalt-60 is stored in a pool below the floor in the facility), shrouded circular source rack, batch type with no automatic handling or product movement systems. The cobalt-60 pencils (COS-43HH) were described as the usual North American C-188 type, but supplied initially by Hungary. GAEC managers said Amersham UK could supply similar pencils from their Russian partners. The facility includes separate product and personnel entry mazes, but the narrow product maze does not seem to be functional and needs renovation. The source hoist is mechanical and located in the ceiling of the facility. The irradiation room is 6 x 5 x 4 meters. In normal operation it is a product overlap design. There are no product turntables so positioning the product around

the source is done by hand, a laborious process that further decreases the operational effectiveness of this facility. However, the facility was reported to be fully functional by GAEC managers.

The irradiation chamber is attached to a control room with a sufficient, but outdated, control panel. There was a separate dosimetry lab which seemed well outfitted; staff demonstrated the use and reading of the various types of dosimeters, including both reference types and the usual production dosimeters. The small warehouse connected to the irradiation chamber had two small cold storage rooms. There was one truck loading dock.

Our recent visit to the GAEC revealed that facility management follows international standard safety procedures for visits and entry to the facility. Some countries require additional security measures such as recording all visitors' names, and requiring that visitors (or a sample of visitors) wear personal dosimeters. Other countries tend to have tighter controls on personnel entry to a facility. New suppliers of cobalt-60 may demand additional safety and documentation procedures. On the other hand, the GAEC irradiation facility is located in a secure campus and visitors were accompanied by security guards, a security precaution not usually seen in other facilities.

### 4.3 Refurbishing the GAEC irradiator

- The vision and purpose of a GAEC semi-commercial irradiator is presented and initial views of refurbishment needs are described.
- An engineering assessment would be required to determine if the GAEC irradiator could be refurbished at less cost than building a new one.
- Achieving the vision will require that a GAEC food irradiation program be refocused and operated as a business, requiring a change in organizational culture for government employees.

An assessment of the feasibility of a commercial irradiator in Ghana should include the possibility of refurbishing and modernizing the GAEC irradiator. A refurbished and refocused GAEC irradiator would serve semi-commercial and research needs, and be suitable for:

- Small-scale commercial irradiation as exporters develop their product volumes;
- Provision of irradiation services to industry;
- Collaborations with other food and nutrition institutes;
- Applied research, including commercial shipping trials;
- Basic research for Ghana and West Africa;
- The development of best irradiation practices for industry leading to Compliance Agreements with importing countries;
- Testing and development of new irradiation applications; and
- A personnel training facility.

There are currently four examples of semi-commercial irradiation facilities. The Canadian Irradiation Centre is a large and very successful semi-commercial, research and training facility located near Montreal. It is a larger facility than would be needed in Ghana. The irradiator at Texas A&M University, an electron beam facility, is primarily doing research and some training. Formerly, the small research irradiator at the Office of Atomic Energy for Peace in Bangkok also did semi-commercial irradiation and research, but its irradiator has become essentially too low powered to be very useful. The Malaysia Institute for Nuclear Technology Research (MINT) now owns and operates a couple of commercial irradiation facilities where they also do research and training.

From a policy perspective, refurbishing the GAEC facility would give Ghana the opportunity to renew its research and development of commercial applications of irradiation. There are new opportunities for Ghanaian pineapple producers to export to the U.S. market. This business cannot realize its full potential without a semi-commercial scale irradiator. A semi-commercial irradiator would allow companies to buy irradiation treatment for their products as they build their export volumes. It would enable realistic larger

scale tests, including shipping trials. It could provide a training institute for Ghana and its West African neighbors. A refurbished irradiator would breathe new life into the Ghana Atomic Energy Commission and justify the modernization of its research capability and output.

Technically, the advantages of considering refurbishment include that the facility chamber and walls are already built and presumably still sufficiently safe for its rated capacity. The walls of the chamber were intact, not crumbling, and with fresh and smooth paint, but an engineering assessment of its rated capacity should be done. The campus has a lot of land, and has good roads leading to it and internally. The facility already has a loading dock, a functioning dosimetry lab, small walk-in cold storage, and trained staff. The warehouse is small but sufficient for small-scale commercial production, especially if logistics were handled efficiently (but not sufficient for quarantine treatments). Staff at the irradiation facility need further training to operate the facility to the cleanliness standards expected of a food processing facility.

Economically, refurbishment of the GAEC would cost considerably less than a new irradiator. The land is currently available and government-owned; the irradiation shield is built (assuming an engineering assessment results in approval of continued safety) and there are already some warehouses and offices in place.

On the other hand, the refurbishment of the irradiator would have to include extensive updating of the equipment, probably to the extent of replacing the entire control panel, safety systems, and the source hoist. The current source hoist is mechanical, attached to the ceiling, and the cables appeared rusty. Pneumatic source hoist systems are safer. New product handling equipment would be needed. Considering the size and current design of the chamber, these might include, at a minimum, roller tracks to move pallet loads of product, and automatic rotating turntables placed around the source rack. Clearly, the cobalt load would have to be increased considerably, probably close to its rated capacity. Since the source rack is old, Hungarian, and designed for Russian cobalt that is probably hard to obtain now, it may have to be replaced as well. With the exception of the South African irradiator, commercial source racks are not usually round; a unique source rack may have to be designed. The facility would have to be completely dose-mapped to research facility standards. There may be other requirements. These observations were made quickly; a separate engineering and radiation safety assessment will need to be done to determine actual refurbishment needs of the facility.

Additionally, to be approved as a facility for quarantine treatment, the facility will need to meet regulatory requirements of the USDA APHIS. Currently, the GAEC warehouse space is insufficient to separate products pre- and post-irradiation. Complete separation is required by regulation (7CFR Part 301.64 – 10 (g) (ii)) (Federal Register February 26, 2003). Chapters 3 and 6 of the USDA Plant Protection and Quarantine Treatment Manual detail this requirement.

USDA would prefer a completely insect-proof separation as well as complete physical separation, but fortunately, under the right circumstances, USDA might agree to a situation that does not offer complete insect-proof separation. The product will have to arrive at the facility in approved pest-proof boxes, and pre- and post-irradiated products in the warehouse will have to be physical separated. Standard operating procedures will have to be approved and followed consistently to assure USDA that there will be no chance of post-processing re-infestation (APHIS Treatment Manual, Chapter 6, p. 6-8-2). This could be done, but as treated volume grows, a larger and properly divided warehouse will probably be required. (Note that the other conditions given by Plant Protection and Quarantine—notably a pest-free zone location of the irradiator with no access by flying pests—are not currently met in Ghana, so the USDA might not allow reliance only on insect-free cartons over the long term.)

In any case, USDA will demand separation of pre-treatment and post-treatment areas in the warehouse as they will otherwise be concerned about inadvertent mixing of cartons. To meet this requirement, the GAEC irradiator would require the construction of a post-processing warehouse, and revised logistics for moving products into and out of the irradiation chamber. Since the GAEC campus is large, there is probably sufficient land for an additional warehouse.

Unfortunately, the GAEC campus is not close to the airport and sea port so shippers would have additional handling to move products. From a regulatory perspective, this location would require very reliable and strictly documented sealing of trucks and other inspection procedures to ensure that only the irradiated

cartons are eventually shipped. USDA will require strict adherence to high security SOPs to approve quarantine treatments at a location so distant from the point of transport.

Frankly, many business people observe that government employees often make poor business decisions. Achieving the vision of a semi-commercial irradiator operated by GAEC will require a shift in organizational culture, management, and agenda. It can happen. One example is the case of Malaysia, where a government institute similar to GAEC now owns and operates a couple of commercial irradiators. One way to encourage business-like behavior in government employees is to make their evaluation and compensation comparable to the private sector, which often translates into higher salaries.

In conclusion, refurbishing the current GAEC irradiator would improve their capacity for research and development, and allow them to service commercial irradiation customers such as pineapple exporters hoping to penetrate the U.S. market. It would give the Ghanaian fresh produce industry a means to conduct shipping trials and would improve the ability of GAEC to train qualified staff. If this very extensive upgrading was accomplished, and an additional warehouse added, and the facility modified to USDA APHIS certification requirements, it could be used for treatment of quarantine pests. A refurbished irradiator and a refocusing of GAEC's food irradiation program could provide true leadership in West Africa.

Lacking engineering evaluations of the current facility and cost comparisons between refurbishment and building a new facility, it is not clear which option is more cost-effective. Several new designs are now available since the GAEC was built and these may have much better product handling efficiency. A later section of this report provides a cost comparison of refurbishment versus the purchase of new irradiators, but this comparison should be updated following further discussions with irradiator equipment suppliers.

Companies that build and maintain irradiation facilities can provide an assessment of the facility and provide a cost comparison for refurbishing the facility versus building a new one. The following companies could do this work (in alphabetical order): Hepro Cape Pty (South Africa) and MDS Nordion (Canada). Additionally, Revis Services (UK) might also be interested in selling the cobalt 60. Annex 1 of this report contains contact information for these companies. There may be other suitable companies as well.

#### 4.4 Personnel training requirements

- Ghana and importing countries require that irradiation facilities be operated and managed by qualified and trained personnel and that the training must be documented.
- Entry requirements for further radiation processing training are described.

Assessing the irradiation training of Ghanaian operators is important for a couple of reasons. First, regardless of who owns and operates the facility, it must be operated safely, and that cannot happen without properly trained and certified staff. Second, U.S. regulations require that food irradiator operators be sufficiently trained, and that the training is documented. Third, the IAEA will not certify the food irradiation facility without sufficiently trained staff.

Although the exact parameters of what constitutes "sufficiently trained staff" are not always defined, at a minimum the following is recommended:

- at least one person who has extensive training in irradiator operations
- at least one Radiation Safety Officer (RSO) for each shift of operation
- additional persons as Dosimetry Technicians
- a quality control/records technician
- a Food Technology Specialist, who has a recognized course of study for the operation of food irradiation facilities and food safety and/or food technology courses, is strongly recommended and may be required by the importing country.

Therefore, at a minimum, four to six well-trained and qualified persons are needed to manage the facility. If the facility will work more than one shift, more than one irradiator operator and RSO is advisable and may be

required by regulations. Several product handlers will also be required, depending on the volume of food to be treated. Product handlers should have at least a short course or in-house training in proper food handling. In addition, secretary/bookkeepers and maintenance staff will be required.

Concerning entry requirements, irradiator operators are managers, often with a college or university degree, but always with considerable experience and training in irradiator operations. Persons can enter RSO training after college or university; a background in physics is common for persons with this job. The Dosimetry Specialist can be trained following college or university; a keen person with a senior high school degree (with specialization in chemistry and/or physics) may also be sufficiently trained.

Irradiation operations training is achieved from most suppliers of irradiation equipment, and usually involves at least three months of training, plus coursework. It is advantageous if the irradiator operator begins training by working with the irradiation equipment supplier during construction and equipment commissioning. RSO training is offered by many universities, from some equipment suppliers, and probably from IAEA and/or GAEC. Dosimetry training can be done through an experienced dosimetry specialist, and following that, attendance at American Society of Testing Materials (ASTM) dosimetry conferences. Additionally, courses in irradiator operation, radiation safety, dosimetry and food irradiation are given at the Canadian Irradiation Centre in Laval, Quebec, and are recognized by the International Atomic Energy Agency, the ASTM and other organizations. The Canadian Irradiation Centre can be contacted at [www.mds.nordion.com](http://www.mds.nordion.com).

The USDA Plant Protection and Quarantine Treatment Manual specifies: “Document the training of key employees on the operation of an irradiation processing facility, applicable to irradiation treatment of agricultural products. All personnel with treatment related responsibilities shall have proper credentials, training and authority for application of irradiation treatments” (USDA PPQ, 2004).

## 4.5 Training Ghanaians for irradiator operations

- Developing qualified Ghanaians through appropriate training.
- Options for obtaining recognized training.

As with most other countries, Ghanaian nuclear control regulations require an irradiation facility to have a Radiation Safety Officer (RSO). Personnel at the irradiation facility operated by the GAEC include a RSO, a dosimetry specialist, and at least in the research institutes, several persons with advanced food technology and food safety knowledge and training.

We cannot estimate how many persons in Ghana might have sufficient training to enable an irradiator operator to hire qualified and well-trained staff. It would be quite unfortunate if the new owner or operator of an irradiation facility could find no qualified staff to hire, as has happened in other countries. However, considering that there are approximately 20,000 students at the University of Ghana, there should be many good candidates suitable for further radiation training. The GAEC hopes to begin a joint degree program with the University of Ghana in nuclear subjects. If this plan comes to fruition, additional persons in Ghana will have the required training. However, the irradiation facilities at GAEC are outdated, and so under the current circumstances it might be very difficult or impossible to achieve the required training in Ghana.

Training could be accomplished by sending qualified Ghanaians to one of several overseas locations for industry short courses, or by offering training in Ghana.

Overseas training facilities include the Canadian Irradiation Centre, the largest, most up-to-date and well-known irradiation training center. Located in Laval, near Montreal, it operates several industry short courses. For years, irradiator operators, dosimetry specialists and food irradiation specialists have trained there. The semi-commercial irradiation facility at Texas A&M University also offers some food irradiation courses. The U.S. National Food Products Association, (formerly the National Food Processors Association), runs an occasional course that would meet the requirements of food irradiation training, but not for operators or dosimetry specialists. One of the authors of this report is the curriculum author and teacher for that course, which could be revised and made available to Ghanaians.



For appropriate training to occur in Ghana, curricula for each course would have to be drafted and tested. The facility would have to be completely refurbished and preferably operate continuously as a research and semi-commercial facility, to allow for sufficient training for operators, managers and dosimetry staff. Appropriately outfitted classrooms would also be needed if the facility offered training.

Improvements in training capacity and in the availability of qualified and trained persons are necessary if the radiation processing sector is to grow. Improving the training capacity of the GAEC would be an advantage for Ghana and other West African countries.

## 5. COST-BENEFIT ANALYSIS OF IRRADIATION

Mean treatment costs<sup>2</sup> (Table 1) have been estimated for two main options of refurbishing the facility at Ghana Atomic Energy Commission and installing new equipment (all costs are reported in U.S. dollars). The treatment cost per tonne for the refurbishment is low, ranging from \$46 for a throughput of 8,250 tonnes to a maximum throughput of 11,000 tonnes. Mean costs for new equipment are much higher, ranging from \$80 and \$98 dollars for maximum throughput, and from \$110 to \$130 for the 8250 tonne throughput. If we take yam as an example of a target commodity for irradiation, the mean costs of a refurbished facility are very comparable to fumigation costs of \$40 per ton. Although the new equipment costs are much higher than these cash fumigation costs, the latter does not take into account the losses due to quality deterioration resulting from methyl bromide fumigation which requires yam temperature be increased.

In terms of profitability, the refurbishment option, whether operated as a purely public facility or as a semi-commercial facility, generates higher returns on investment (internal rates of return of 29%, with an 8% corporate tax, to 33%) than the scenarios with new equipment. Estimates of benefit to cost ratios from operating of the facility with new equipment are less than one, and internal rates of return are negative.

These estimates suggest that refurbishment of equipment at the GAEC facility is the better option. Future commercial operation of a new facility could still be profitable because of higher levels of throughput, and the economies of scale associated with higher capacity sources such as the 300 kCi and 500 kCi cobalt-60 sources. Besides, the analysis here assumes the maximum dosage of 1000 Gy which pushes costs to the maximum as well. Mean dosage will probably fall between 400Gy and 800 Gy, reducing actual treatment costs.

**Table 1. Summary of mean treatment costs (U.S. dollars/tonne)**

Scenario	Throughput	
	Maximum throughput = 11,000 tonnes	60% current yam exports = 8,250 tonnes
Refurbishment	34	46
New Equipment	98	131
New Equipment with Supplier's costs	81	109

<sup>2</sup> Assumptions underlying mean cost estimates are presented in Table 2.

**Table 2. Summary of estimates of investment returns**

Scenario	Investment indicator	Discount rate assumptions			
		15%	10%	5%	2.5%
Refurbish as public facility	B/C ratio	1.93	-	-	-
	IRR (%)	33	-	-	-
Refurbish for semi-commercial facility	B/C ratio	1.74	-	-	-
	IRR (%)	29	-	-	-
Equipment upgrade operated as public facility	B/C ratio	0.59	0.67	0.77	-
	IRR (%)	-19.00	-15.00	-11.00	-
New equipment with supplier's costs operated as public facility	B/C ratio	0.71	0.81	0.92	0.98
	IRR (%)	12.00%	-8.00	-3.00	-1.00

B/C = Benefit Cost ratio; IRR = Internal Rate of Return

Assumptions applied in estimating Mean Treatment Costs:

1. Facility at GAEC is to be refurbished, not replaced with a 100 kCi cobalt source.
2. Costs of investments are taken from Diop et al., 2002, (Feasibility study of a multipurpose food irradiation facility in Senegal) with following adjustments to reflect refurbishments.
3. No costs charged for irradiation chamber.
4. Costs of conveyor and auxiliary equipment are estimated at 50% of cost of new installation.
5. Office, warehouse and refrigeration are upgrades but cost is maintained at \$500,000 because of expansion of warehouse.
6. No costs charged for new building.
7. Salaries are estimated for category of staff indicated in table below. Salaries are based on the gross incomes of the most senior staff at the facility now and increased by 40% to reflect more realistic rates for the quality of staff required for such a facility.
8. Annual Co-60 replacement is at 12.5% of initial cost of the energy source.
9. Maintenance is 2% of total initial investment costs.
10. Utility costs are 4% of initial investment costs.
11. Depreciation of conveyor and auxiliary equipment is based on a 10-year amortization.
12. Depreciation of Co-60 is based on 15-year amortization.
13. Depreciation of office and warehouse is at 25-year amortization.
14. A 15% interest on loan (initial investment) is included as cost.
15. An annual profit of 20% on operating costs is allowed.
16. A maximum throughput of 11,000 tons of produce will be processed per year.
17. Maximum dosage is 1 kGy.

**Table 3. Estimates of mean treatment costs (scenario of refurbishing GAEC irradiator)**

<b>Investment cost</b>	<b>Amount US Dollars (thousands)</b>	
Co- 60 Source	182	
Irradiation Chamber (Already present)	0	
Conveyor and Auxiliary equipment (for refurbishing)	800	
Office, warehouse & refrigeration UPGRADE	500	
Building (not needed now) present one valued at \$20,000	20	
<b>Total Initial Investment cost</b>	<b>1482</b>	
<b>Operating costs</b>		
Salaries & Supplementary costs	62	
Co -60 replenishment	23	
Maintenance	30	
Miscellaneous (Water, electricity, insurance, communication)	59	
Depreciation (conveyor +aux. 10yr amortization)	80	
Depreciation (Cobalt- 60, 15yr amortization)	12	
Depreciation (buildings, 25yr amortization)	21	
Interest on loan at 10% for 10 years	29	
<b>Total Operating Costs</b>	<b>316</b>	
Annual required profit (20% of operating costs)	63	
<b>Total Operating Costs plus profit</b>	<b>379</b>	
<b>Per tonne treatment costs</b>		
Mean Treatment cost at maximum throughput = 11,000 t./kGy	0.034	
Mean treatment costs of 30% of current yam exports (4125 tonnes)	0.092	
Mean treatment costs of 60% of current yam exports (8350 tonnes)	0.046	
<b>Packhouse data on current yam exports</b>	<b>Monthly</b>	<b>Annual</b>
Current yam exports - 50,000 boxes x 25 kg/box per month	1250	13750
30 percent of current	375	4125
60 percent of current	750	8250

**Table 4. Analysis of refurbishing GAEC facility with public sector investment (100 kCi Co- 60 source).**  
 Scenario 1: Public sector investment (Costs and revenues in thousand dollars)  
 (no corporate tax; discount rate = 15%)

Year	Capital costs	Operating costs	Total costs	Revenue	Discount factor@15%	Present value of costs	Present value of revenue	Net revenue
0	1482	0	1482	0	1	1482	0	-1482
1		316	316	1100	0.8696	275	957	682
2		316	316	1100	0.7561	239	832	593
3		316	316	1100	0.6575	208	723	515
4		316	316	1100	0.5718	181	629	448
5		316	316	1100	0.4972	157	547	390
6		316	316	1100	0.4323	137	476	339
7		316	316	1100	0.3759	119	414	295
8		316	316	1100	0.3269	103	360	256
9		316	316	1100	0.2843	90	313	223
10		316	316	1100	0.2472	78	272	194
11		316	316	1100	0.2149	68	236	169
12		316	316	1100	0.1869	59	206	147
13		316	316	1100	0.1625	51	179	127
14		316	316	1100	0.1413	45	155	111
15		316	316	1120	0.1229	39	138	99
Total						3330	6435	
Discount rate = 15%					B/C ratio	1.93		
					NPV	3105		
					IRR	33%		
Discount rate =12%					B/C ratio	2.06		
					NPV	3862		
					IRR	36%		

NPV = Net Present Value

**Table 5. Analysis of refurbishing GAEC facility with private commercial investment (100kCi Co-60 source).**

Scenario 2. Private commercial investment (costs and revenues in thousand dollars)  
(Corporate tax of 8% on profits, discount rate =15%)

Year	Capital costs	Operating costs	Total costs	Rev	Discount factor @15%	PV costs	PV rev	Net rev
0	1482	0	1482	0	1	1482	0	-1482
1		379	379	1100	0.8696	329	957	627
2		379	379	1100	0.7561	286	832	545
3		379	379	1100	0.6575	249	723	474
4		379	379	1100	0.5718	217	629	412
5		379	379	1100	0.4972	188	547	359
6		379	379	1100	0.4323	164	476	312
7		379	379	1100	0.3759	142	414	271
8		379	379	1100	0.3269	124	360	236
9		379	379	1100	0.2843	108	313	205
10		379	379	1100	0.2472	94	272	178
11		379	379	1100	0.2149	81	236	155
12		379	379	1100	0.1869	71	206	135
13		379	379	1100	0.1625	62	179	117
14		379	379	1100	0.1413	54	155	102
15		380	380	1120	0.1229	47	138	91
Total						3697	6435	
B/C ratio						1.74		
NPV						2738		
IRR						29%		

**Table 6. Scenario of installing new equipment at GAEC**

<b>Investment cost</b>	<b>Thousand U.S. Dollars</b>	<b>Thousand U.S. Dollars</b>
Co -60 Source 100 kCi	200	
Irradiation Chamber (already present)	800	
Refurbish control and Auxiliary equipment	4000	
Office, warehouse & refrigeration UPGRADE	500	
Building value of existing one (new building not needed now)	50	
<b>Total Initial Investment cost</b>	<b>5550</b>	
<b>Operating Costs</b>		
Salaries & Supplementary costs		62
Cobalt-60 replenishment		25
Maintenance		111
Miscellaneous (water, electricity, insurance, communication)		222
Depreciation (conveyor +aux. 10 year amortization)		400
Depreciation (Cobalt-60, 15 year amortization)		13
Depreciation (buildings, 25 year amortization)		22
Interest on loan (initial investment) at 10% for 10 years annuity payments		90
<b>Operating costs</b>		<b>884</b>
Annual required profit (20% of operating costs)		177
<b>Total Operating Costs</b>		<b>1060</b>
Maximum Throughput = 11,000 t./kGy	11,000	
<b>Mean cost of irradiation kGy per ton</b>	<b>\$96.38</b>	

**Table 7. Investment analysis of purchasing new equipment  
(costs and revenues in thousand dollars)**

Year	Investment	Operating costs	Total costs	Revenue	Discount factor@15%	Present value of costs	Present value of Revenue	Net revenue
0	5550	0	5550	0	1	5550	0	-5550
1		884	884	1100	0.8696	768	957	188
2		884	884	1100	0.7561	668	832	164
3		884	884	1100	0.6575	581	723	142
4		884	884	1100	0.5718	505	629	124
5		884	884	1100	0.4972	439	547	108
6		884	884	1100	0.4323	382	476	94
7		884	884	1100	0.3759	332	414	81
8		884	884	1100	0.3269	289	360	71
9		884	884	1100	0.2843	251	313	62
10		884	884	1100	0.2472	218	272	54
11		884	884	1100	0.2149	190	236	47
12		884	884	1100	0.1869	165	206	40
13		884	884	1100	0.1625	144	179	35
14		884	884	1100	0.1413	125	155	31
15		884	884	1120	0.1229	109	138	29
					Total	10716	6435	-4282
0% corporate tax								
Discount rates								
	15%	10%	5%	2.5%				
B/C ratio	0.60	0.67	0.78	0.83				
NPV	-4282	-3899	-3293	-2856				
IRR	-18%	-15%	-10%	-8%				



## 6. AGRICULTURAL PRODUCTION AND EXPORT DEVELOPMENT

This section summarizes production statistics and logistics of trade for each of the likely food irradiation candidates identified previously, as well as some other potential commodities.

These statistics are important to this project as a measure of what can be done, even when trade windows to the U.S. have not been opened. The production and European Union export statistics tell us that Ghana can grow commodities that meet EU standards for quality (as stringent as the U.S.) and phytosanitary requirements (less stringent than the U.S.). The companies currently involved in exports have accomplished transportation and market channel logistics and established commercial trade arrangements.

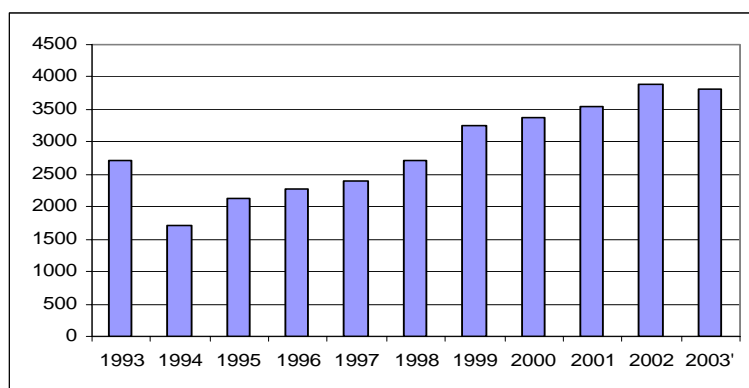
The statistics do not capture potential trade with the U.S. if the use of a quarantine treatment such as irradiation were made available.

Fortunately, export development programs currently in place in Ghana will support improvements in agricultural production, product quality, cold-chain logistics, centralized packhouses, and resolve export transportation and market channel issues. USAID has three programs in place that are addressing these problems with the goal of improving trade with the U.S.: The West Africa Trade Hub (the sponsor of this project), the West Africa Regional Program (the sponsor of the pest risk assessment work), and the Trade and Investment Program for a Competitive Export Economy (working on agricultural production and market quality improvements). Each of these programs is funded, staffed, and operational. Furthermore, the U.S. government has recently announced an additional \$3 million commitment to improving agricultural production through the Millennium Challenge Account Award.

### 6.1 Yam

Yam is produced in the central belt of Ghana, covering the forest-savannah transition and the savannah zones. These regions are located more than 300 kilometres from Accra. Area planted to yam has increased steadily from about 150,000 ha in 1994 to 320,000 ha in 2003. Production has increased correspondingly from 2.7 million tons to 3.8 million tons over the same period (see Figure 1). This represents an average annual growth of about 7%.

**Figure 1. Yam production in Ghana (metric tonnes)**



Production is seasonal. The main harvest season is August to December. The period May to July is the lean season. Production in the north is harvested a little later than that in the Brong Ahafo Region in central Ghana and this helps to extend the marketing season a bit longer. Traditionally, farmers store the produce in pits for use or sale later.

Yam is marketed through a network of yam traders and their agents who assist the traders in identifying sources of the produce (see Table 8). Traders visit farms or markets in producing areas to buy yams and transport them on trucks to markets in the main consuming centers in the south, such as Kumasi, Accra, and Takoradi.

**Table 8. Main actors in the Ghanaian yam market**

Type of Trade	Description
Producer-sellers	Farmers may sell own produce in the market (in the village, rural market or road side). They may sell to wholesalers or fulfill the wholesale functions themselves.
Rural local assemblers	Based in villages or rural towns. They may buy direct from farmers, bulk up and sell to itinerant traders.
Rural- based itinerant wholesaler	Based in the village markets. They buy from farmers in their region and transfer to rural town markets or urban markets. Sell to retailers or sedentary wholesalers.
Urban- based wholesaler	Based in the urban markets. They buy from farmers in their region, usually with the services of an agent, and transfer to urban markets. Sell to retailers or sedentary wholesalers.
Trader's agent	Based in the rural or producing area. They identify location of yams to be purchased, and inspect the quality and size of the yam on behalf of the trader. They are paid a commission for this service.
Sedentary wholesaler	Based in village, rural town or urban market. They buy from producer/sellers and both types of itinerant wholesalers and sell to smaller wholesalers or retailers in the same market.
Sedentary retailers	Based in the village, rural town or urban market. They buy from producer/sellers and both types of itinerant wholesalers and sell to retailers or consumers.
Itinerant retailers	Buy from farmers, various types of wholesalers or retailers, and take to nearby market or to the roadside to sell to consumers.

Source: Bancroft, 2000.

Yam produced in the Northern Region is transported to Accra along the eastern corridor, either through Hohoe and Akosombo in the Volta Region, or down the Volta River from Kete Krachi in the Volta Region, to Akosombo and then to Accra. Yams from the north to Kumasi may either go through Yeji, Atebubu, and Ejura to Kumasi or through Tamale to Kumasi. Although the first route is shorter, only about 270 km, compared to 509 km from Tamale to Kumasi, it is unreliable because of irregularity of the ferry crossing at Yeji over the Volta River. Yams produced in Brong Ahafo are transported to markets in Techiman, Kumasi or Accra. The roads from Techiman through Kumasi and to Accra are in good condition.

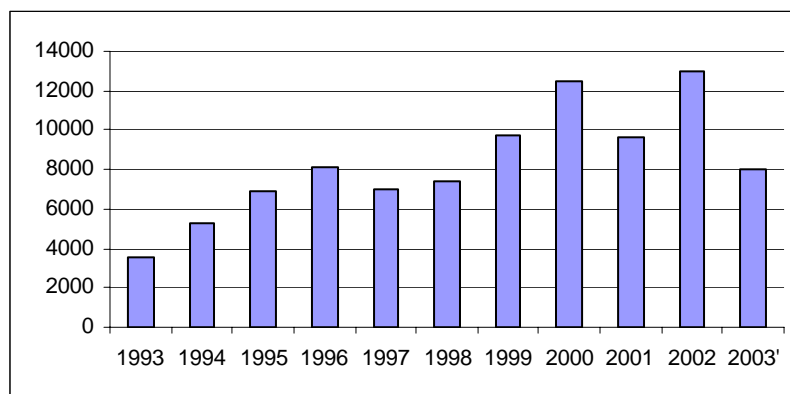
Yam exporters, all of whom operate from Accra, do not grow yam and few buy directly from farmers. Exporters purchase yam from sedentary wholesalers based in the main yam markets in Accra (Konkomba, Agboghloshi and Baasare markets). With the increased competition in the yam export market, some exporters now commission yam itinerant traders to purchase yam from the production areas.

The major causes of post-harvest loss in yam are weight loss (due to evapo-transpiration accentuated by sprouting), rotting (due to fungal and bacterial pathogens), insect infestation and sprouting (Bancroft, 2000).

Yam exporters need effective ways of delaying sprouting, and controlling microbial infection and insect infestation. Bancroft (2000) also reports that yam does not respond to the most commonly used sprout-suppressants. At the moment, yam is fumigated on landing at U.S. ports. But the temperatures at which fumigation are done leads to deterioration in the quality of yam. This is why irradiation could be a pre-shipment treatment option.

The yams are cleaned, wrapped in newsprint and packed in boxes of 25 kg net weight for export to Europe and North America. In 2004, Ghana exported only 7.8% of the total value of her yam exports to the U.S. market. Available data on export volumes up to 2003 show a high level of variability, culminating in a 39% decline in exports between 2002 and 2003 (see Figure 2). The yam export business suffered from lack of coordination, leading to flooding of Ghanaian yam and collapse of prices in the destination markets. The designation of yam as a traditional export crop, establishment of a packhouse at the port, and institution of a quota system, have helped to rationalize the yam export trade. Export volumes have risen again and current estimate of annual exports is 15,000 tonnes. Most shipment is now by sea although there is a government directive for air shipment of yam to North America.

**Figure 2. Yam exports from Ghana (metric tonnes)**



## 6.2 Cocoyam

Cocoyam is an edible corm<sup>3</sup>; and the leaf is also eaten as a vegetable. Major growing areas are the forest and forest-savannah transition zones of southern Ghana. The crop is seasonal and has an 8-12 month maturity period.

Average annual output over the period 2000-2003 was 1.7 million tons. Small amounts of cocoyam are being exported, but there are no data on export volumes. The GAEC has been testing the irradiation of cocoyam.

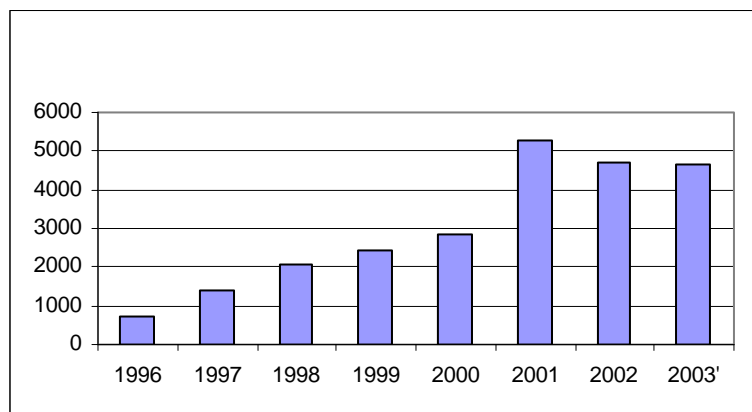
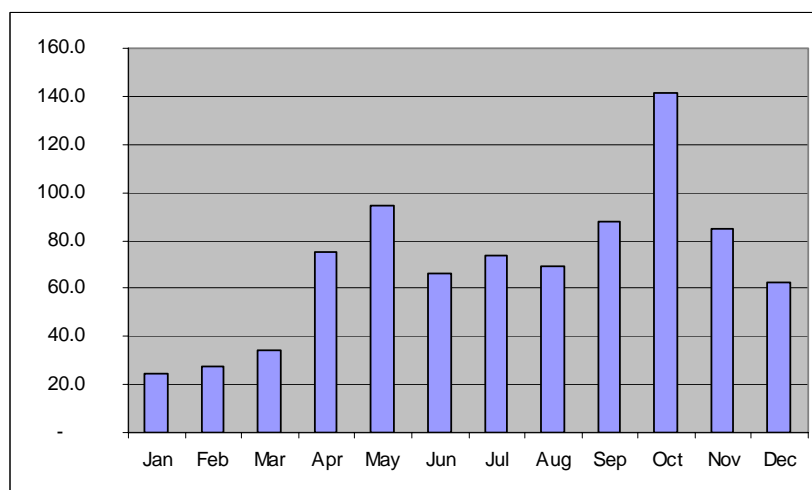
The marketing of cocoyam is similar to that of yam but simplified by the absence of itinerant traders and urban wholesalers.

Cocoyam flowing into Accra, Kumasi, Takoradi and other urban centers normally comes from the closest producing area. So, cocoyam supplied to Accra is likely to be produced in the Eastern Region, while Takoradi is supplied by the Western Region.

## 6.3 Chili pepper

Chili pepper is a high value export crop that has rapidly increased its export volumes since the mid-1990s (see Figure 3). Although it is grown across the country, production in Tema and West Dangme Districts is sourced for exports because of proximity to the ports. The chili shrub fruits seasonally, but producers are able to sustain fruiting with irrigation. Although exports flow every month, the period of significant export activity is April to December with peaks in May and October (see Figure 4).

<sup>3</sup> This is the edible part of the root of the plant.

**Figure 3. Exports of chili pepper from Ghana (tonnes)****Figure 4. Seasonality of chili exports from Ghana in 2004 (metric tonnes)**

The yields are between 1000 – 1250 kg/ha for fresh pod, which yields 350 – 500 kg/ha of dried chilies. The produce is sold either directly to individuals, especially the Ghanaian expatriate community via hotels, restaurants, and companies, or to market women who sell in the open markets or to supermarkets.

Exporters buy fresh chilies directly from farmers, and dried chilies from farmers or traders' markets. Current air freight charges are \$6.02/kg for red chilies and \$5.69/kg for green chilies. About 840 tonnes (FOB value of 23,000 Euro) was exported to the EU in 2004. The exports go to ethnic markets. Supply is steady from April to December. However, Ghana presently does not grow the preferred variety because of lack of appropriate seed.

## 6.4 Onions and shallots

Large onions, commonly known as Bawku Red, are produced in the Upper East region, while shallots are produced in the southern parts of the Volta region, around Keta. Ghana also imports significant quantities of large white onion varieties from Niger and Mali, and these are also suitable candidates for export. The yield of regular onions is about 5 tonnes/ha while shallots yield 9 – 10 tons/ha.

Sprout prevention is the major problem that farmers and traders face, currently countered effectively with steaming. However for larger quantities, use of steam may be limiting. Besides, steaming does not prevent onion rot, which is a major problem in storage. Controlling onion rot with irradiation should be explored.

## 6.5 Mango

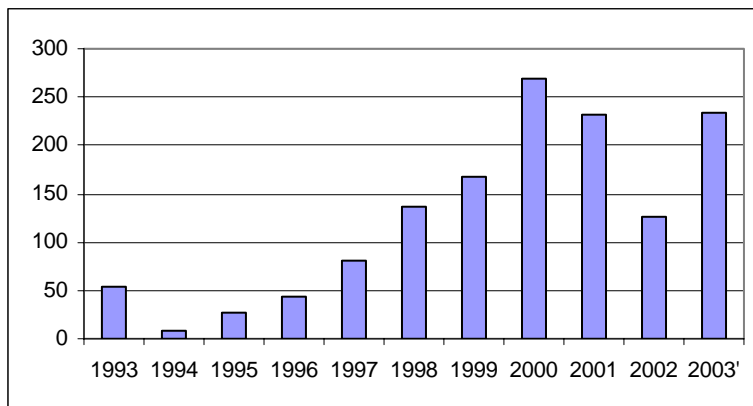
Mango is produced in several parts of the country. There are two main varieties, the traditional stringy variety and the large and fleshy exotic varieties. The latter includes Haden, Keitt, Kent, and Palmer, all suited to the export market.

Organized mango production for export is centered around Dangbe West (Dodowa), very close to Accra, and parts of Eastern region (along the Akwapim Range). Although the main mango season runs from April through June, choice of variety can help to stagger harvests throughout the year and enable producers to target export market windows more effectively. Also, new mango plantings north of Tamale are expected to have a February to July harvest season.

The main phytosanitary problems for mango are anthracnose, fruit flies, and the mango seed weevil. Irradiation tests have been conducted on extermination of the seed weevil, fruit flies, and on delaying ripening. Prior research shows that a warm water dip for 5 minutes (50° - 55° F), followed by irradiation can control anthracnose.

Mango is a new non-traditional export crop; only 340 tonnes were exported to the EU in 2004 (see Figure 5). The varieties grown for export are the Kent and Keitt. Demand for mango in the EU is increasing, and importers consider Ghanaian mangos to be highly desirable. However, Ghana has to address quality issues to be able to grow in that market. The market leaders are Brazil (with 80%-90% share), Côte d'Ivoire, Senegal, Mali and South Africa. Ghana has the advantage of two mango seasons to sustain year-round export supply.

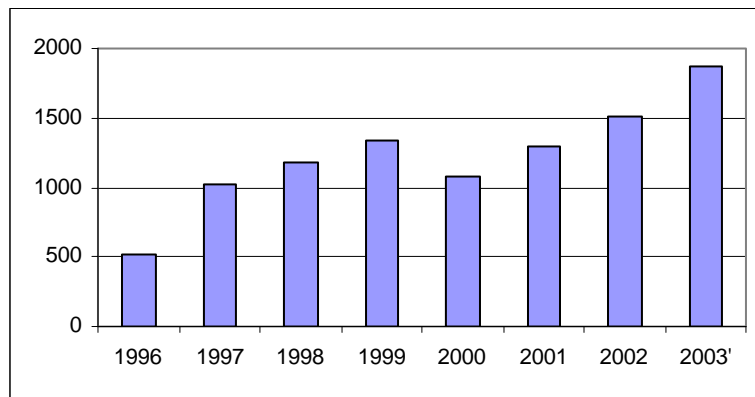
**Figure 5. Exports of mango from Ghana (metric tonnes)**



## 6.6 Garden egg

Garden eggs are small, round, white eggplants. Their interior texture and flavor is very similar to purple eggplants (aubergine). When eaten raw, garden eggs are crisper. Exports of the vegetable have increased steadily since 2000 from about 1100 tonnes to about 1850 tonnes in 2003 (see Figure 6).

**Figure 6. Exports of eggplant from Ghana (metric tonnes)**



## 6.7 Pineapple

Pineapple is the leading non-traditional export crop. It is grown in southern parts of the Eastern region (mainly Akwapim South District), and Central region (about a 100 -150 km radius of the air and sea ports). Production is by large commercial farmers as well as smallholders. Some large commercial farmers produce for export. Most exporters source the fruit from smallholders. It is estimated that 60% of fruits exported are supplied by smallholders. Exporters may also contract smallholders to produce pineapple. Such contracts, also known as outgrower schemes, give the exporter the first option to purchase fruit from the grower.

The smallholders also supply the fruit to local processors or traders for the local fresh fruit market, depending upon the price relativities between export and the local market, and the producers' perceptions about the reliability of the export market in terms of timeliness of payments.

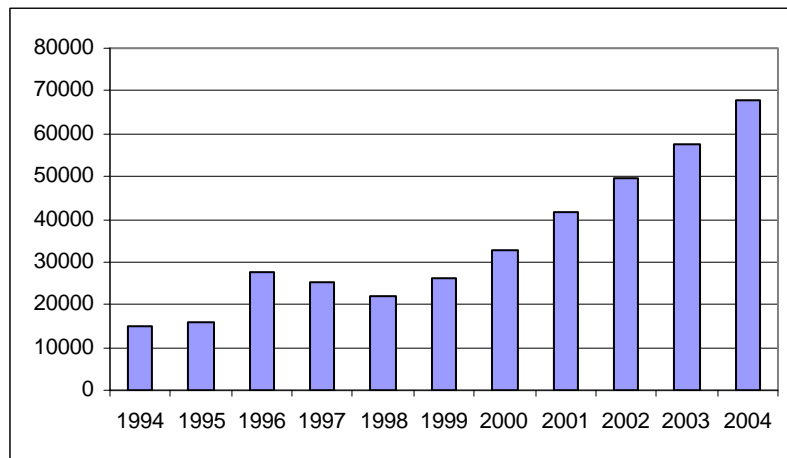
The crop takes about 18 months from planting to mature. Although the crop can be planted any time of the year, the main harvest period is May-July. Large farmers tend to irrigate, therefore seasonality of harvests is reduced.

A smallholder delivers fruit to the exporter's packhouse where treatment and packaging prepare the fruit for the port. Fruits are exported either by air or by sea. There is interest in whether irradiation could be used to delay ripening/senescence and therefore allow for less expensive sea shipment. Fruits not selected for export (export rejects) are sold on the local market.

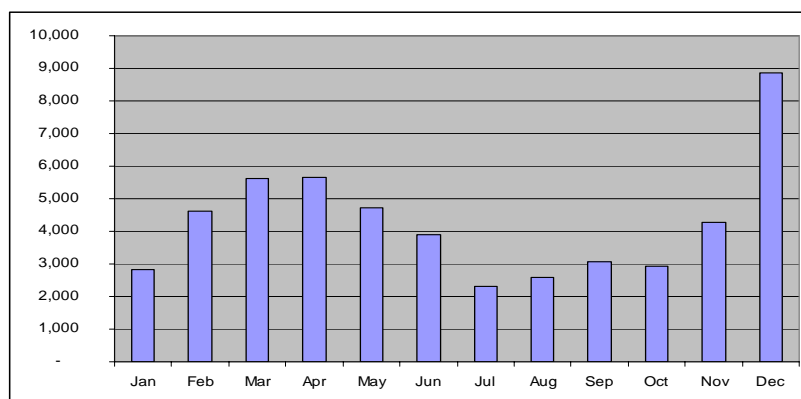
In 2004, Ghana exported about 55,000,000 tonnes of pineapple (see Figure 7) with an FOB value of 415,000 Euros. The main destination of Ghana's pineapple is the EU, specifically, Belgium, France, the UK and Italy. The major players in this market are Costa Rica and Cote d'Ivoire, with Ghana in the third position. Although Ghana is able to supply the market year-round, there are two clear seasons. Exports peak in September and December and dip in January, after which supply increases again up to June. Ghanaian farmers are presently moving away from their traditional Smooth Cayenne variety to the MD2, which is now the preferred variety on the international market and fetches nearly four times the price of Smooth Cayenne. MD2 changes color nicely upon ripening, but the flavor of the Smooth Cayenne is sweeter. Availability of cold-chain facilities enables producers to harvest more mature Smooth Cayenne fruit, thereby allowing the sugar level to build up, and ensuring its continued acceptance as a quality product on the market.

Monthly export data for pineapple in 2004 shows constant shipments throughout the year, with a minor season occurring between July and October (see Figure 8).

**Figure 7. Exports of pineapple from Ghana (tonnes)**



**Figure 8. Seasonality of pineapple exports from Ghana in 2004 (metric tonnes)**



## 6.8 Papaya

Papaya (called “pawpaw” in Ghana) is produced commercially but with organized production centered around Dangbe West (Dodowa). A recent study identified 17 farmers in the area producing for exports, but production is highly concentrated with a single operator, who holds 92% of the total land cultivated by the 17 farmers (Tachie, 2005).

As a result, although the number of farmers increased from six in 2000 to 17 in 2003, the total crop area only increased from 204 ha to 215 ha. Output has increased from about 2000 tons in 2000 to 7600 tons in 2003.

First stage harvesting of papaya is possible within 9 to 10 months. However, previous problems with high yield losses due to non-bearing trees are being resolved through improvements in agricultural production practices, chiefly through the use of irrigation.

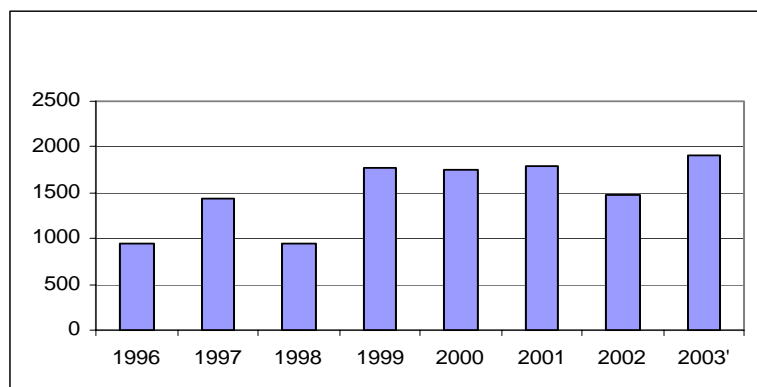
Ghana exported 1885 tonnes of papaya (valued at 55,000 Euro FOB) in 2003 (Figure 9). The country is yet to establish itself in the papaya market. The market leader now is Brazil, followed by Cote d’Ivoire. The main

export destinations are the UK, the Netherlands and Germany. Ghanaian farmers are shifting from the Solo variety to the market-preferred Brazilian Golden variety because of its color.

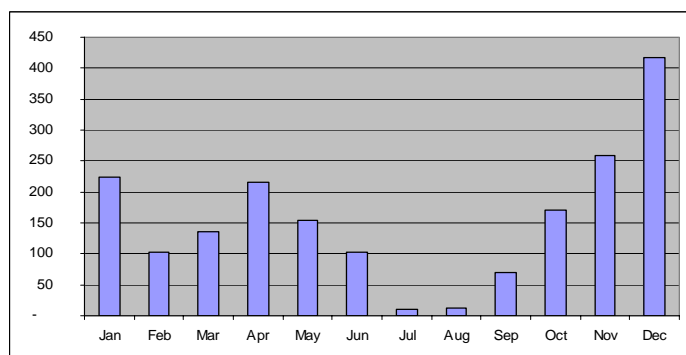
Papaya is a very high-value crop but it requires irrigation and thus presents a challenge to prospective producers. Only four companies now produce the crop for export. Most shipment of papaya is by air.

The monthly export data in 2004 shows an increase in shipments from September to December (see Figure 10). The period with least export activity is July to August.

**Figure 9. Exports of papaya from Ghana (metric tonnes)**



**Figure 10. Seasonality of papaya exports from Ghana in 2004 (metric tonnes)**



## 6.9 Vegetables

Vegetables are exported primarily to ethnic markets in the UK. In general, vegetables are not seasonal. Most vegetable exports are the so-called Asian vegetables, packed into boxes and air-freighted to European specialty markets. Asian vegetables are indigenous to the Far East, and were introduced into Ghana by Indian migrants. Eight of the 12 Asian vegetables exported are not consumed by Ghanaians. They are grown specifically for export specialty markets and are handled differently. EurepGap quality and sanitary requirements have not yet affected the marketing of these vegetables.

Four of the Asian vegetables are consumed by Ghanaians: chili peppers, okra, green beans, and aubergines (long, slender purple eggplants). They are grown more widely in Ghana and can be handled by the usual export methods.



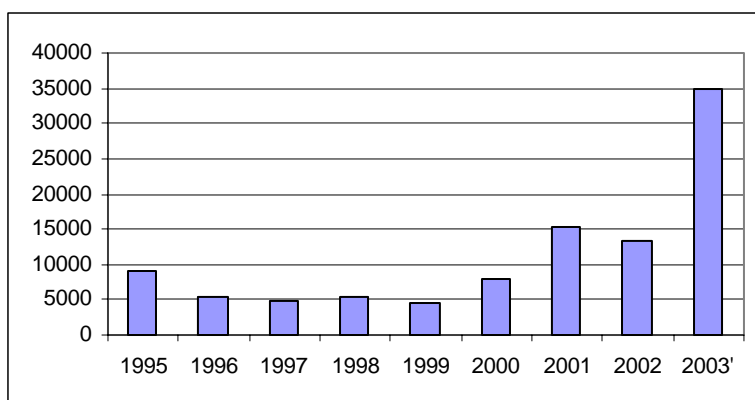
There are two marketing channels: producer to consumer (60%), and producer–through trader–to consumer or final user (40%).

There is a vegetable producer association, the Vegetable Producers and Exporters Association of Ghana (VEPEG), but membership is optional.

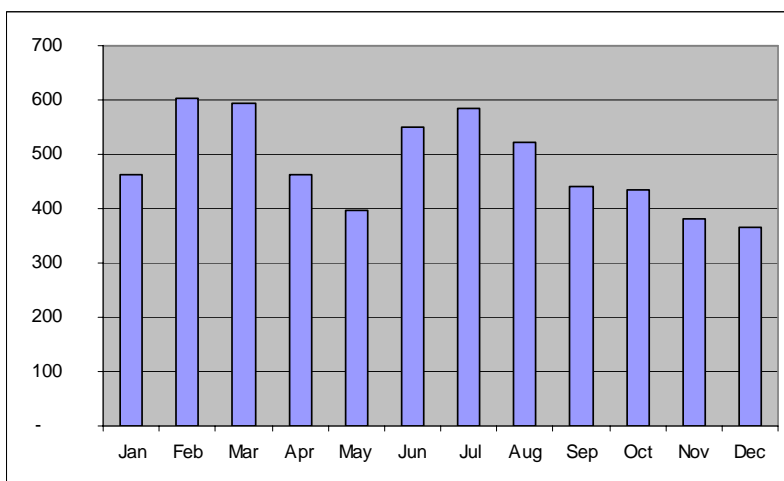
In 2004, about 5,800 tonnes of produce (FOB value of 75,000 Euro) was exported (see Figure 11). Small volumes of sweet potatoes were exported to the U.S. in 2003 (\$4,400) and in 2004 (\$27,900).

Export activity tends to be steady throughout the year as shown in Figure 12. Ghana is second to Kenya in terms of export volumes, but quality improvements are necessary if Ghanaian exports are to lead the market.

**Figure 11. Exports of vegetables from Ghana (metric tonnes)**



**Figure 12. Seasonality of vegetable exports from Ghana (metric tonnes)**

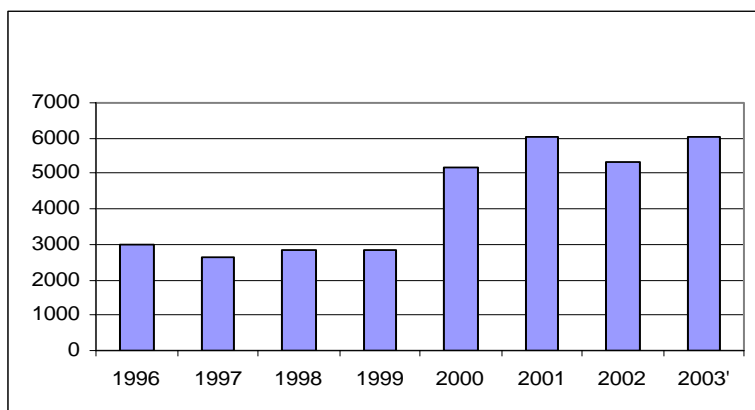


## 6.10 Smoked fish

Sources of smoked fish include the Volta region, particularly southern Volta, Greater Accra, Central (Cape Coast area) and Western (Takoradi) regions. Figure 13 shows a positive trend in export volumes from 1996 to 2003.

Fish dealers also supply producers of spicy fish sauces (locally known as 'shito') who may then irradiate before use.

**Figure 13. Exports of processed fish from Ghana (tonnes)**



**Table 9. Trends in exports of agricultural commodities from Ghana (metric tonnes)**

Year	Yam	Papaya	Mango	Eggplant	Chili pepper	Assorted vegetables	Banana	Pineapple	Smoked fish
1993	3574	NA	53	NA	NA	NA	47		NA
1994	5322	NA	9	NA	NA	NA	583	14954	NA
1995	6866	NA	26	NA	NA	9000	1856	15764	NA
1996	8086	949	43	515	732	5477	3295	27603	3008
1997	7018	1430	80	1018	1420	4731	4008	25124	2660
1998	7421	936	136	1184	2088	5333	2905	21941	2832
1999	9763	1780	167	1338	2420	4580	3383	26155	2859
2000	12463	1748	268	1080	2819	7948	3883	32677	5198
2001	9630	1792	232	1295	5281	15330	3251	41428	6027
2002	13025	1474	126	1512	4687	13418	3233	49700	5328
2003	7973	1917	234	1867	4674	34764	3635	57392	6043
2004	NA	1885	227	NA	NA	5801	NA	68000	NA

Source (all export data reported here): Ministry of Food and Agriculture (2004) Facts and Figures; Horticulture Export Industry Initiative Project, Ministry of Food and Agriculture.

# ANNEX 1. BASICS OF FOOD IRRADIATION & EQUIPMENT SUPPLIERS

Irradiation can be used to resolve some, but not all, food processing problems. It uses radiation energy, either generated by cobalt-60, electron beam accelerators, or X-rays generated by electron beam accelerators.

Radiation energy is very penetrating; energy from radioisotope sources or from the X-ray energy generated by electron beam accelerators will penetrate boxes and even pallet loads, depending on the product density. This property means that irradiation facilities have to be designed to ensure a consistently high level of safety. Radiation energy is very damaging to living organisms; fortunately, the radiation processing industry has an excellent safety record. The same process and equipment are used to sterilize medical disposables, cosmetics, personal care goods and numerous industrial items worldwide. There are over 200 radioisotope-based irradiators in commercial use worldwide. Since the plastics and wire industry also use high-energy electron accelerators, they number in the thousands.

From a biological perspective, radiation energy works by creating fast chemical changes that occur when double bonds or water molecules are broken, forming short-lived free radicals that break cell walls and disrupt cell metabolism. To a lesser degree, radiation energy is also effective by disrupting the DNA in living things. Generally, however, its ability to break cell walls in pests and microorganisms is what makes it effective.

From a food processing perspective, irradiation can stop sprouting of roots and tubers, control (by killing or sterilizing) insects and pests, kill harmful and spoilage bacteria, and result in other benefits such as delayed ripening. The technique has been successfully applied to a wide range of fruits, vegetables and plant products, to herbs, spices and other dry ingredients, to meat, shrimp and poultry (fresh and frozen), to roots and tubers of many plants, and to grains and cereals. Although some cheeses have been irradiated to control bacteria, dairy products, in general are not tolerant of the process. Some food packaging materials, and especially dairy packaging materials, are irradiated when empty, to ensure they are clean before filling.

From a food quality perspective, this ability to break bonds in cell walls is a two-edged sword. When cell walls are broken, enzymes are released, which can hasten ripening and spoilage. Fruits and vegetables must be high quality and undamaged prior to irradiation, or it can hasten spoilage. Poultry, crustaceans and meat have to be refrigerated and can be frozen before irradiation to help ensure best quality. Irradiated foods have to be stored in the same way as non-irradiated foods.

From a nutritional perspective, irradiation is one of the least harmful of all the food processes. All food processes, and even simple storage and cooking, reduce food nutrients. The extent of loss of nutrients depends on the food, the environmental conditions of the food, and the dose, or irradiation treatment level, and occasionally other factors. So, fruits and vegetables which are irradiated with the lowest dose, experience little or no measurable nutrient losses. Herbs and spices, because they are dry, are irradiated with the highest dose we use, but because they are dry they lose very few nutrients. The irradiation of some meats, crustaceans and poultry can result in the loss of some B vitamins, notably thiamine. But these losses are much less significant than other food processes, and can be reduced by freezing or having the meat product very cold when irradiating. Protein and carbohydrates are not affected by irradiation. Nevertheless, the fact that irradiation can cause nutrient losses is well understood and was considered in the approval of irradiation for phytosanitary purposes. Good food processing procedures for irradiation should be documented to ensure nutrient losses are minimized, and food quality maximized.

Since irradiation is sometimes an unfamiliar process to food marketers and consumers, irradiated foods are labelled. Market trials and consumer information are recommended.

There are three basic types of food irradiation equipment: cobalt-60 or radioisotope source, electron beam accelerators, or X-ray. Each type of equipment has advantages and disadvantages, but for a multi-purpose food irradiator in Ghana, we recommend a cobalt-60 radioisotope source.

Cobalt-60 is a radioisotope formed when cobalt is placed in a high neutron flux and absorbs neutrons. Cobalt-60 is made in power reactors. It has a half-life of about 5.26 years, meaning that if the irradiator source is not replenished in five years it will have half its original power. In practice this means that the irradiator should add about 12% of its initial cobalt-60 source each year just to maintain its source strength. Cobalt-60 degenerates to nickel-60, a non-radioactive isotope. Several countries manufacture cobalt-60, including Canada, Russia (sold through Reviss Services), and Argentina.

Several companies supply irradiation equipment and the cobalt-60 energy source. Suppliers of cobalt-60 will also repatriate the spent sources when no longer needed. Spent sources are recycled or put in long-term storage. Suitable equipment suppliers with a brief description are listed below. Other companies may also provide services and equipment. For Ghana, it will be important to ensure that the supplier can provide the right equipment, training, maintenance and other services to ensure the project's success.

- Canadian Irradiation Centre. [www.mds.nordion.com](http://www.mds.nordion.com).
- Hepro Cape Pty. Designed, built and operates the Hepro service irradiator near Cape Town, South Africa. A small irradiator, but a real workhorse in a long-time commercial operation. Contact Rocco Basson ([astrauss@worldonline.co.za](mailto:astrauss@worldonline.co.za)).
- MDS Nordion. The designers and builders of most of the world's radioisotope irradiation facilities for food and medical uses, and the largest supplier of cobalt-60. Has built 120 commercial irradiation facilities. Located in Ottawa, Ontario, Canada. Contact [Richard.Wiens@mdsinc.com](mailto:Richard.Wiens@mdsinc.com) or [Daniel.levesque@mdsinc.com](mailto:Daniel.levesque@mdsinc.com) or [www.mds.nordion.com](http://www.mds.nordion.com).
- Reviss UK. A spin off from Amersham UK, and long-time supplier of irradiation processing equipment and cobalt-60 through its two companies, Puridec (for equipment) and Reviss Services (for cobalt-60). Contact [corporate@reviss.co.uk](mailto:corporate@reviss.co.uk) or [www.reviss.com](http://www.reviss.com).

## ANNEX 2. CONTACTS

Name and Organization	Contact information
<b>Can and Kaa Limited</b> <b>Food Processing and Export</b> Mr. Kofi A. Asiedu President CEO	P.O. Box 15474 Accra-North, Ghana Tel: 233-21-400746 Fax: 322-21-400663 Cell: 233-0244-340746 cankaa@africaonline.com.gh
<b>Farmapine Ghana Limited</b> Mr. Christian Foli Managing Director	P.O. Box NW 772 Nasawam, Ghana Tel: 233-0-0832-22467 Tel: 233-0244-331-041 Cell: 233-0244-340-746 farmapine@ghana.com
<b>Ghana Atomic Energy Commission</b>  Dr. Victoria Appiah Deputy Director General Ghana Atomic Energy Commission  G. Emi-Reynolds Rose Boatin Josephine Nketsia-Tabiri P.O. Yeboah C.E. Annoh Sur Michael Osae	P.O. Box JG 80 Legon Accra, Ghana Tel: 233-21-401323  Cell: 233-024-318-1003 vicappiah@yahoo.com  Radiation Protection Institute Food Sci and Rad Processing Biotech and Nuclear Ag Research National Nuclear Research Institute Entomologist BINARI/GAEC Entomologist BINARI/GAEC
<b>Ghana Standards Board</b> Fred Gyamera Head of Standards Ghana Standards Board	Cell: 0277405989 Tel: 233-021-501961 to 65
<b>Marcotte Consulting LLC</b> Michelle Marcotte International Irradiation Project Consultant	10104 East Franklin Ave Glenn Dale, Maryland 20769 USA Tel:301-262-9866 Cell: 301-204-2399 marcotteconsulting@comcast.net
<b>University of Ghana</b> Dr. Ramatu Al Hassan Department Head Agricultural Economics and Agribusiness National Irradiation Project Consultant	Cell 020-815-4570

Name and Organization	Contact information
<p><b>USAID Trade and Investment Program for a Competitive Export Economy (TIPCEE)</b> Jean Michel Voisard Export Business Development Director</p> <p>Charles Ofori Addo Lead Business Development Specialist</p>	<p>Ground Floor Codemm House 1<sup>st</sup> Dzorwulu Crescent, West Airport PMB CT 330 Accra Ghana Tel: 233-21-775-350 Tel: 233-21-775-790 Fax: 233-21-775-293 Cell: 233-0244-313146 jvoisard@tipceeghana.org</p> <p>Cell:233-0244-614-543 Caddo@tipceeghana.org</p>
<p><b>USAID West Africa Regional Program</b> Dr. Shawn Robertson Phytosanitary Advisor on loan from USDA-APHIS</p>	<p>E 45/3 Independence Ave P.O. Box 1630 Accra Ghana Cell: 233-244-311932 Tel: 233-21-228-440 srobertson@usaid.gov</p>
<p><b>USAID West Africa Trade Hub</b></p> <p>Vanessa Adams Export Business Development Director</p> <p>Kofi Humado Agricultural Trade Specialist Irradiation Project Leader Member of Parliament</p> <p>Andy Cook Director</p> <p>Leah Quin Communications and Outreach Coordinator</p>	<p>Jubilee House 4<sup>th</sup> Street, Kuky Hill, Osu C/O USAID P.O. Box 1630 Accra Ghana</p> <p>Tel:233-21-733-393 Tel:233-21-781-608 Fax: 233-21-782-231 Cell: 233-0243-161-274 vadams@watradehub.com</p> <p>Cell: 233-0244-310-142 khumado@watradehub.com</p> <p>Cell: 233-0244-310-148</p> <p>233-0244-119-587 lquin@watradehub.com</p>
<p><b>USDA APHIS</b> Scott Wood, Director Treatment Quality Assurance Unit Center for Plant Health Science and Technology</p> <p>Dr. Inder Paul Ghad Treatment Specialist Phytosanitary Issues Management USDA Plant Protection and Quarantine</p>	<p>1730 Varsity Drive Suite 400 Raleigh, NC 27606-5202 USA Tel: 919-855-7400 Fax: 919 855-7477</p> <p>4700 River Road, Unit 140 Riverdale, Maryland 20737-1236 USA</p>

# REFERENCES

- Appiah V., Nketsia-Tabiri J., Bansa D., Montford K.G., Sakyi Dawson E., Al-Hassan R., Edwards J. (2002) Techno-economic feasibility of food irradiation in Ghana. In: Study of the impact of food irradiation on preventing losses: Experience in Africa. Proceedings of the final research coordination meeting held in Pretoria, South Africa, 20-24 September 1999. IAEA TecDoc 1291. pp 17-33.
- Bancroft, R.D. (March 2000) Relieving post-harvest constraints and identifying opportunities for improving the marketing of fresh yam in Ghana. Crop Post Harvest Programme of UK Department for International Development. Report #R6505; ZB No. ZB0016. 51pp.
- Banini G.K., Emi-Reynolds G. (1998) Comparative study of the variables for determining unit processing cost of irradiating food products: A case study of Ghana. Journal of Applied Science and Technology. Vol 3, Nos 1&2. pp 29-38.
- Diop Y., Marchioni E., Kuntz F., Ba D., Hasselmann C. (2002) Feasibility of setting up of a multi-purpose food irradiation facility in Senegal. In: Study of the impact of food irradiation on preventing losses: Experience in Africa. Proceedings of the final research coordination meeting held in Pretoria, South Africa, 20-24 September 1999. IAEA TecDoc 1291. pp 47-59.
- Federal Register. (February 26, 2003) Volume 68, No 38. pp 8817-8820. 7CFR Part 301 Mexican Fruit Fly, interim rule and request for comments.
- Follett, P. (June 20, 2005) End of mission report for phytosanitary treatment for insect pests infesting fruits and vegetables (Project and Task Number BGD5024-01-01). IAEA, Department of Technical Cooperation, Austria.
- IAEA (May 2002) Study of the impact of food irradiation on preventing losses: Experience in Africa. Proceedings of the final research coordination meeting held in Pretoria, South Africa, 20-24 September 1999. IAEA TecDoc 1291.
- Ministry of Food and Agriculture, Ghana (2004) Agriculture in Ghana. Facts and figures (2003). Statistics, Research and Information Directorate. September 2004.
- Ministry of Trade and Industry, Ghana. (July 6, 2004) Notice to Exporters of Fresh Yam. Facilitation of Export Trade of Fresh Yam from Ghana.
- Tachie, Raymond (2005). Financial analysis of pawpaw production (a case study of Ga District, Ghana). MPhil thesis submitted to the Department of Agricultural Economics & Agribusiness for examination (Unpublished). Department of Agricultural Economics & Agribusiness, University of Ghana, Legon.
- USDA Plant Protection and Quarantine. 2002-2004 Treatment Manual. Chapter 6, Certifying Facilities; pp 6-8-1 to 6-8-4.
- USDA Plant Protection and Quarantine. 2002-2004 Treatment Manual. Chapter 3, Non-Chemical Treatments Irradiation; pp 3-8-1 to 3-8-16.
- Voisard JM., Jaeger, P. (2003) Ghana horticulture development study. Including agriculture sub-sector investment program restructuring. Prepared for ESSD Department of the World Bank.