Efficacy of Electron Beam Irradiation of Processed Pork Products

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Abstract:

The research reported on in this paper was conducted as part of a larger project. That project is on-going and is focused on ascertaining if irradiation of processed meats would be effective and economical. It involved the examination, through modeling, of the irradiation of one of many currently produced ready-to-eat (RTE) convenience-oriented, value-added pork products, sliced boneless ham. The results and findings reported in this paper represent the initial estimates of the cost and potential profitability or economic viability of irradiation of processed meats. The results and findings in this paper should be considered preliminary with extension and verification to be reported in a later paper by the authors. The objective of the portion of that project reported on in this paper was to conduct cost analysis of alternative irradiation methods and to ascertain the cost of each of those methods.

Three scenarios were considered for cost analysis. The first scenario was the installation of an X-ray irradiator at an existing meat processing plant. The second scenario was the installation of a Cobalt-60 irradiator at an existing meat processing plant. The third scenario assumed that the meat processor contracted for irradiation services from an off-site company providing such service to a number of clients.

For purposes of this study it was assumed that irradiation of sliced boneless ham would result in either a $.06/pound reduction in costs from processor to consumer, a $.06/pound increase in willingness to pay [price] or an equivalent combination of reduced costs and increased price. Total cost per pound for the irradiation process applied to sliced boneless ham ranged from $0.008, at the 200 million pound annual throughput rate using Cobalt-60 irradiation, to $0.069 at the 50 million pound annual throughput rate when contracting with an off-site company.

Motivation:

The research reported on in this paper was conducted as part of a larger project. That project is on-going and is focused on ascertaining if irradiation of processed meats would be effective and economical. It involved the examination, through modeling, of the irradiation of one of many currently produced ready-to-eat (RTE) convenience-oriented, value-added pork products, sliced boneless ham. The results and findings reported in this paper represent the initial estimates of the cost and potential profitability or economic viability of irradiation of processed meats. The results and findings in this paper should be considered preliminary with extension and verification to be reported in a later paper by the authors.

The function of irradiation of food products is to reduce or destroy microorganisms, parasites, or insects (Andrews et al., 1998). Irradiation of fresh meats has obvious applications considering the relatively short shelf life of these products due to susceptibility to microbial contamination. Over the past fifteen years RTE meat products have been the topic of much research (Kurth, L., 1983; Cordray et al., 1986; Boles and Parrish, 1990; Chen and Trout, 1991a, 1991b). Few sources of research findings, however, are available regarding the application and effects of irradiation on the quality and cost of processed meats.

Brewer et al. (1994) reported that as consumer concerns for food safety increased, so did concerns about product shelf stability and microbial contaminants. Consumer concerns have increased with the growing number of reported food borne illnesses and food product recalls. It has been well documented that ionizing radiation can effectively reduce or remove microbial contaminants in meat products and extend product shelf stability in the process (Murano, 1995; Olson, 1998; Thayer et al., 1992; Radomyski et al., 1994). When this research was conducted the Food and Drug Administration had not yet approved the irradiation of processed meat products (Federal Register, 1999) and few sources of research findings were available with regard to the application and effects of radiation on the quality and cost of processed meats.

Objective:

This research was conducted as part of a larger project designed to ascertain the safety, quality, and palatability characteristics of radiated processed meat products and to determine if irradiation of processed meats might be warranted. The objective of the portion of that project reported on in this paper was to conduct cost analysis of alternative irradiation methods and to ascertain the cost of each of those methods. The effectiveness of irradiation in reducing spoilage microbes, as well as assessment of changes to product quality, and sensory evaluations will be reported on in later papers. This report focuses on the alternative methods of irradiation of processed meat products and the preliminary results and findings of an analysis of the potential economic viability of those methods.

Terms Used:

The following are some of the terms used in this paper. Some may not be well known by the reader and are defined here.

- Curie (Ci): Unit quantity of any radioactive nuclide in which $3.7 * 10^{10}$ disintegrations per second occur.
- Economic Engineering Approach: A methodology for estimating costs and returns utilizing a hypothetical set of inputs and production relationships based on known production techniques and practices, equipment prices, and yield information (Foster et al., 1981, cited by Edon, 1994). Mathematical relationships developed by agricultural

economists and using information from academic and industry experts to estimate typical costs for a given machine.

- Gamma Ray Photons originating from the 10 billion K portion of the electromagnetic field.
- High-energy Electron Beam Accelerator Instrumentation that converts electricity into highly energetic energy source by "crowding" electrons together and focusing them in a stream.
- Internal Rate of Return (IRR): The discount rate (interest rate) that equates the present value of a project's expected cash inflows to the present value of the project's costs. Or, the discount rate that makes the net present value of all relevant cash flows for a project equal to zero. The internal rate of return may have multiple values when the stream of net benefits alternates from negative to positive more than once.
- Irradiation Process of applying ionizing energy to a product.
- Kilograys (kGy): One thousand grays. The old term is rad. One gray equals one joule of energy absorbed per kilogram of absorber.
- Million Electron Volts (MeV): One electron volt equals $1.6*10^{-13}$ joules of energy.
- Net Present Value: It uses discounted cash flow techniques. It finds the difference, in this case for investment in a project, between the discounted present value of expected cash inflows and the discounted present value of expected cash outflows. It is the recommended method for evaluating most business investments. In this method, the expected incremental cash inflows and outflows of a proposed project are discounted by a required rate of return in order to obtain the net present value of the proposal. The discount rate is often assumed to be the cost of capital experienced by the investor.

- Radiation Product of ionizing energy.
- X-Ray Photons originating from the 100 million K portion of the electromagnetic field.

Methods:

Three scenarios were considered for cost analysis. The first scenario was the installation of an X-ray irradiator at an existing meat processing plant. The second scenario was the installation of a Cobalt-60 irradiator at an existing meat processing plant. The third scenario assumed that the meat processor contracted for irradiation services from an off-site company providing such service to a number of clients.

Cost analysis of irradiation of processed pork products on a commercial scale was conducted using industry data provided by experts from companies that manufacture irradiation equipment suitable under scenarios one and two. For the third scenario, price information was gathered from companies that offer off-site food irradiation services and. transportation costs were ascertained using information from companies that transport refrigerated and frozen meats.

The economic engineering approach, utilizing the information provided by experts, was used to ascertain the cost of irradiation for each scenario at several alternative rates of annual throughput. For the purpose of this study the cost of irradiation of sliced boneless ham was examined at four annual throughput rates: 50, 100, 150, and 200 million pounds of sliced boneless ham.

Results:

The financial benefits from irradiation of processed meats are not known. For purposes of this study it was assumed that irradiation of sliced boneless ham would result in either a

$.06/pound reduction in costs from processor to consumer, a $.06/pound increase in willingness to pay [price] or an equivalent combination of reduced costs and increased price. The Net Present value (NPV) and Internal Rate of Return (IRR) for each of the four rates of throughput and for each of the three scenarios were calculated. When used to make accept/reject decisions, a project should be accepted when NPV is greater than zero, and the IRR is greater than the cost of capital (Gitman, 2000; Barry, et al., 2000). Here the project was considered to be profitable if the NPV was positive. A 10-year project time horizon was considered to be appropriate and the weighted average cost of capital was assumed to be 15 percent. Buildings and equipment were assumed to be sold for expected salvage value at the end of the 10-year time horizon.

Results indicate that irradiation of sliced boneless ham using an X-ray irradiator (Scenario 1) would be a profitable business for annual throughputs of 100, 150, and 200 million pounds per year, but not, however, for a throughput rate of 50 million pounds per year. A business implementing a Cobalt-60 irradiator (Scenario 2) would be profitable even at the lowest throughput of 50 million pounds. The highest net present value, see Table 1, was generated by the 200 million pound rate using Cobalt-60 irradiation. In general, these results are similar to the findings of Morrison (1989) and Bogart & Tolstun (1999) in that irradiation costs per pound declined at higher annual throughput rates. Contracting with an off-site company (Scenario 3) was profitable for throughput rates of 150 and 200 million pounds per year. Total cost per pound for the irradiation process applied to sliced boneless ham ranged from $0.008, at the 200 million pound annual throughput rate using Cobalt-60 irradiation, to $0.069 at the 50 million pound annual throughput rate when contracting with an off-site company.

When contracting radiation and transportation services to irradiate 50 and 100 million pounds per year, the model displayed negative values for net income before taxes and net present value because irradiation plus transportation charges exceeded the assumed $ .06 per pound revenue. Those results are not shown in Table 1.

See the Tables in the Appendix for more on the assumptions and the results for the Scenario of irradiation of 200 million pounds per year of sliced boneless ham using an X-ray irradiator.

Table 1. Net Profits, Net Present Value, Internal Rate of Return and Total Cost per Pound of Irradiation Processing of Sliced Boneless Ham Using an X-ray Irradiator, Cobalt-60 Irradiator, and Contracting Irradiation services.

Volume of sliced ham irradiated (Million pounds)	**Net Profit after Tax & Interest (Dollars)**	**Net Present Value (Dollars)**	**Internal Rate of Return (%)**	**Total Costs ($ per pound)**
		X-ray Irradiator	**Scenario 1**	
50	$ 638,214	$(170,237)	15%	$ 0.0407
100	$ 2,554,796	$ 9,434,060	35%	$ 0.0213
150	$ 4,471,379	$19,038,358	53%	$ 0.0148
200	$ 6,387,962	$28,642,655	71%	$ 0.0116
		Cobalt 60 Irradiator	**Scenario 2**	
50	$ 1,146,131	$ 3,435,091	27%	$ 0.0253
100	$ 3,035,932	$12,794,146	54%	$ 0.0140
150	$ 4,925,731	$22,153,201	78%	$ 0.0102
200	$ 6,815,531	$32,367,799	100%	$ 0.0084
		Contracting for Irradiation Services	**Scenario 3**	
150	$ 117,393	$ 552,149	44%	$ 0.0589
200	$ 807,787	$ 4,086,227	196%	$ 0.0539

Implications:

While profitability is essential for economic survival, other factors may also be important when choosing an irradiation technique. The FDA has allowed three types of ionizing radiation to be used on foods: Gamma rays from radioactive isotopes such as Cobalt-60, high energy electrons, and X-rays. The three types of radiation methods have similar effects at the molecular level, but differ technically and may differ in terms of public perception. For instance, Gamma rays (measured in Curies) have the advantage of high penetration of the target product. This type of radiation technique can easily treat pallet loads. An important characteristic of Cobalt-60 radiation is that it continually radiates and decays --- it cannot be turned off so it is active regardless of production schedules. It is estimated that approximately 12.5% of Cobalt-60 decays annually and therefore must be replenished, plus there is some risk of environmental contamination (Morrison, 1989).

The radiation produced by electron beam accelerators (measured in MeV) is generated by electricity. No radiation is produced when the power is turned off and, under normal operations, no radioactive material is transported, handled, or discarded. The major disadvantage to electron beam accelerators is their more limited ability to penetrate foods. At the levels allowed and approved by the FDA, electron accelerators cannot penetrate more than 1 to 3 inches of food products, depending on food density (Morrison, 1989). Therefore, it may be necessary, when using electron beam irradiation, to treat product before it is packed in pallet-configured loads for treatment and final shipping.

Electron beam radiation can be converted to X-ray radiation and in this way achieve greater penetration of the target product. Foods then could be radiated in thicker loads such as pallets or shipping boxes. The disadvantage to X-ray radiation is in the low level of efficiency of use of electricity. At 5 million electron volts (the highest level approved by the FDA for conversion to X-ray) only 7% to 8% of the original electron beam power is available for treating the food products with the resulting X-rays (Cleland, 1989, Cited by Morrison, 1989). This naturally results in higher per pound electricity costs than the with electron beam irradiation.

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APPENDIX

Technical and Economic Data and Assumptions:

The Tables in this Appendix contain more details on the assumptions and the results for the Scenario of irradiation of 200 million pounds per year of sliced boneless ham using an X-ray irradiator. Some data on the other scenarios is presented were necessary. The reader is reminded that the results and findings reported in this paper represent the initial estimates of the cost and potential profitability or economic viability of irradiation of processed meats. The results and findings in this paper should be considered preliminary with extension and verification to be reported in a later paper by the authors.

This project used the economic engineering approach, which is a method of estimating costs and returns by explicitly identifying data and assumptions and completing a cash flow analysis for a particular project or enterprise. This method includes a hypothetical set of inputs and production relationships based on known production techniques and practices, equipment prices, and yield information (Foster et al., 1981, cited by Edon, 1994). The authors implemented the economic engineering approach in a model on Microsoft Excel 2000® based on a computer simulation originally designed by O'Rourke (2002).

The information provided by the experts and several assumptions from other authors were explicitly incorporated into the worksheet. The model was used to evaluate the three mutually exclusive scenarios: an integrated X-ray irradiator, an integrated Cobalt-60 irradiator, and contracting irradiation services from a company that provided those services off-site. Common inputs and assumptions for the three scenarios are shown in Table 2. Additional inputs and assumptions were used for the third scenario for contracted irradiation. Those assumptions included: loading and unloading charges, transport charges per mile, fuel surcharge, maximum truck load, distance from the processing plant to the irradiation facility, and time spent on transportation.

Table 2. Data and Assumptions for Irradiation of Sliced Boneless Ham Under Three Scenarios

Processed meat product:	Sliced boneless ham	
Packing material	Oxygen impermeable bags	
Shipping box material	Cardboard	
Condition of the meat	Refrigerated	
	Unit	**Data**
Refrigeration temperature	f	30-34
Density	g/cm3	0.8
Minimum dose	kGy	1.5
Maximum dose	kGy	2.0
Dimensions of the shipping boxes	Inches	20*16*8
Volume of a shipping box	Cubic feet	1.48
Net weight of a shipping box	Lbs	70.5
Weight of one box and vacuum bags	Lbs	1.5
Gross weight per shipping box	Lbs	72.0
Dimensions of a pallet	Inches	40*48*72
Volume of a pallet	Cubic feet	80.0
Number of shipping boxes per pallet	Boxes	54
Net weight per pallet	Lbs	3,806
Gross weight per pallet	Lbs	3,887
Minimum volume to be processed	Lbs/year	50,000,000
Maximum volume to be processed	Lbs/year	200,000,000
Operating shift	Hours/year	2,000

<u>Operating Costs</u>:

The electricity price per kWh was $0.03799, which was the rate for the intermediate power service provided by the local power company, Illinois Power.

The fixed costs were: Shift supervisors and product handlers, permanent personnel, fixed fee for use of electricity, fixed maintenance, fees and licenses, insurance and property taxes, operating interest, and long term interest expense. According to Morrison (1989) one shift supervisor and two product handlers are able to deal with a volume of seven pallets per hour, which is the equivalent of 54 million pounds per shift per year. Meanwhile, one shift was assumed to be 2000 hours (7.7 hours per day, 5 days a week and 52 weeks per year). Permanent personnel consisted of a plant manager, a radiation safety/quality control officer, and a clerical person with annual salaries of $50,000, $30,000, and $20,000, respectively.

The power company charged an annual fixed fee of $22,800. Fixed maintenance is assumed to be 35% of the total maintenance. Fees and licenses were estimated at $5,000 per year. In addition, insurance and property taxes were assumed to be 2% of the initial total cost of the facility. The operating interest was calculated based on 7% interest on operating capital and 15% of operating loan as a percentage of cash expense. Finally, the long-term interest expense was estimated according to the long-term liabilities and the interest on long-term borrowing. In this example the long-term liabilities were assumed to be 60% of the initial total investment cost of the facility and the interest on long-term borrowing was assumed to be 12%.

Initial Investments:

The experts that provided information for this study agreed that the initial investment for the equipment, system components, and land would vary considerably because each particular irradiator model had specific requirements. For instance, the X- ray irradiator type assumed in this economic model would require an 85’ by 70’ building costing $238,000. On the other hand, the building that would house the cobalt-60 irradiator would cost $372,000 (based on an area of 71*131 feet). The cost per square foot for the irradiators’ buildings was assumed to be $40. For offices, lab, and control room the cost assumed was assumed $55 per square foot. Initial investments for land, forklifts, and refrigerated warehouse were assumed to be zero because these items were already part of the production system before the irradiation process was installed.

The rest of the items required for the irradiation process and their respective initial investment costs are shown in Table 3. Initial equipment and building investments were the same for the four throughputs using the X-ray irradiator.

Table 3. Investment and Depreciation for Buildings and Equipment for Irradiation of 200 Million Pounds of Sliced Boneless Ham Using an X-ray Irradiator.

Item description	Estimated life	Initial investment	Annual SL depreciation	Book value at end 10th year	Salvage Value at end of 10th year
	Years	Thousand Dollars			
Irradiator Building	20	$238	$11	$ 131	$95
Offices, Lab, and control room	20	$ 83	$ 4	$45	$33
Biological shielding	20	$1,000	$50	$ 500	$ 0
Refrigerated warehouse	0	$ 0	$ 0	$ 0	$ 0
Land	0	$ 0	$ 0	$ 0	$ 0
Machine accelerator	10	$7,500	$ 675	$ 750	$ 750
X-ray converter	10	$500	$45	$50	$50
Conveyor system	10	$1,200	$ 108	$ 120	$ 120
Air handling and cooling system	10	$350	$32	$35	$35
Dock doors and levelers	10	$ 20	$ 2	$ 2	$ 2
Spectrophotometer	5	$ 12	$ 2	$0	$0
Computer system	5	$5	$ 1	$0	$0
Forklifts	0	$ 0	$ 0	$0	$0
Total		$ 10,908	$ 929	$ 1,633	$ 1,085

<u>Depreciation</u>:

Annual depreciation was calculated using the straight-line method, subtracting the estimated salvage value from the initial investment and dividing the remainder by the years of estimated life (Table 3). Generally, the salvage value was determined as a percentage of the initial investment, however, for the biological shielding the salvage value was assumed to be zero. An ending market value equivalent to 40 % of their initial investment was assumed for irradiator buildings, offices, labs, and control rooms. Irradiation experts were the source of the estimated useful lives of the items required for the irradiation process.

Revenue:

The total revenue was determined by the total annual throughput multiplied by an assumed price premium per pound of product. The authors do not claim any research support on which to base the higher-price/lower-cost premium. In this study, it was assumed that the irradiated product would have value to the processor equivalent to $ 0.06 per pound retail. The analysis could be done with or without that assumption; however, approach was employed to help clearly see the impact of irradiation on potential profitability.

Net Present Value and Internal Rate of Return:

The NPV was calculated for the investment in the irradiation process assuming a 10-year time horizon and a period using a weighted cost of capital of 15 percent. Buildings and equipment were assumed to be sold for salvage value at the end of the 10-year time horizon.

The NPV was found by subtracting the project's initial investment (time zero) from the present value of its future net cash inflows discounted at a rate equal to the business' cost of capital. When the NPV is used to make accept-reject decisions, the decision criteria is if the NPV is greater than $0, accept the project; if the NPV is less than $0, reject the project (Gitman, 2000). And, generally, when the IRR is used to make accept-reject decisions, the decision criteria is if the IRR is greater than the cost of capital, accept the project; if the IRR is less than the cost of capital, reject the project (Gitman, 2000).

Table 4. Annual Pro Forma Income Statement for the Irradiation of 200 Million Pounds of Sliced Boneless Ham Using an X-ray Irradiator.

Factor	Unit	Figure	Factor	Unit	Figure
Shifts required		4	Throughput per year	Million pounds	200
Hours per shift	Hours	2,000	Throughput per hour	Lbs/hr	25,000
Total Revenue	$ 12,000,000		Additional revenue	$/Lb	0.06
			Annual Operating hours	Hours	8,000

Expenses:	Total Dollars	Percent total cost (%)	Percent total revenue (%)
Plant manager	50,000	2.15	0.42
Radiation safety officer	30,000	1.29	0.25
Clerical person	20,000	0.86	0.17
Shift supervisors	100,000	4.31	0.83
Product handlers	160,000	6.89	1.33
Electricity used by irradiator	123,094	5.30	1.03
General use of electricity	20,059	0.86	0.17
Fixed maintenance	13,125	0.57	0.11
Variable maintenance	24,375	1.05	0.20
SL Depreciation	929,123	40.03	7.74
Fees and licenses	5,000	0.22	0.04
Insurance and property taxes	15,582	0.67	0.13
Miscellaneous expense	39,267	1.69	0.33
Estimated operating interest	6,305	0.27	0.05
Total operating expense	1,535,929		12.80
Interest expense	785,340	33.83	6.54
Total expense	2,321,269	100.00	19.34
Net profit before tax	9,678,731		80.66
Taxes (Corp. rate)	3,290,768		27.42
Net Profit After Tax & Interest	6,387,962		53.23

Table 5. Cash Flow Analysis, in Dollars, for the Irradiation of 200 Million Pounds of Sliced Boneless Ham Using an X-ray Irradiator

Item	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Revenue		12,000,000	12,000,000	12,000,000	12,000,000	12,000,000
Incremental Cash Expense		600,501	600,501	600,501	600,501	600,501
Fixed Cash Expense		416,507	416,507	416,507	416,507	416,507
Variable Cash Expense		183,994	183,994	183,994	183,994	183,994
Depreciation (SL)		929,123	929,123	929,123	929,123	929,123
Net Taxable Revenue		10,470,376	10,470,376	10,470,376	10,470,376	10,470,376
Income Tax		3,559,928	3,559,928	3,559,928	3,559,928	3,559,928
After Tax Revenue Flow		6,910,448	6,910,448	6,910,448	6,910,448	6,910,448
Depreciation Expense		929,123	929,123	929,123	929,123	929,123
Net Operating Cash Flow		7,839,571	7,839,571	7,839,571	7,839,571	7,839,571
Initial Investment	-10,907,500					
Salvage Value at the end of 10th year						
Book Value at the end of 10th year						
Gain or (Loss)						
Tax Inc (DECR)						
Net Cash Flows						
Change NWC	-144,980					
Term Year Non-Operating Cash Flow						
Net Cash Flows	-11,052,480	7,839,571	7,839,571	7,839,571	7,839,571	7,839,571

Table 5 (continued). Cash Flow Analysis, in Dollars, for the Irradiation of 200 Million Pounds of Sliced Boneless Ham Using an X-ray Irradiator

Item	Year 6	Year 7	Year 8	Year 9	Year 10
Revenue	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000
Incremental Cash Expense	600,501	600,501	600,501	600,501	600,501
Fixed Cash Expense	416,507	416,507	416,507	416,507	416,507
Variable Cash Expense	183,994	183,994	183,994	183,994	183,994
Depreciation (SL)	929,123	929,123	929,123	929,123	929,123
Net Taxable Revenue	10,470,376	10,470,376	10,470,376	10,470,376	10,470,376
Income Tax	3,559,928	3,559,928	3,559,928	3,559,928	3,559,928
After Tax Revenue Flow	6,910,448	6,910,448	6,910,448	6,910,448	6,910,448
Depreciation Expense	929,123	929,123	929,123	929,123	929,123
Net Operating Cash Flow	7,839,571	7,839,571	7,839,571	7,839,571	7,839,571
Initial Investment					
Salvage Value at the end of 10th year					1,085,200
Book Value at the end of 10th year					1,633,275
Gain or (Loss)					-548,075
Tax Inc (DECR)					-186,346
Net Cash Flows					1,271,546
Change NWC					144,980
Term Year Non-Operating Cash Flow					1,416,525
Net Cash Flows	7,839,571	7,839,571	7,839,571	7,839,571	9,256,096
Net Present Value at 15%	$28,642,655				
Internal Rate of Return	71%				