Low-Dose Irradiation: A Promising Option For Trichina-Safe Pork Certification

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Abstract

The parasitic nematode *Trichinella spiralis*, the causative agent of pork trichinosis, has long been a blemish on the U.S. public health record. Trichinosis remains a problem in the U.S. today, both as a threat to human health and as an expensive stigma on the U.S. pork industry. Progress in swine management since 1950 has improved the situation, but today the U.S. still has one of the highest rates of trichinosis among the industrialized nations.

A promising method for rendering pork noninfectious for trichina is gamma irradiation. Extensive research on the irradiation of trichina-infected meat has indicated that the parasitic disease cycle could be effectively broken by relatively low levels of radiation. Most researchers agree that a dose of 0.3 kGy (30 krad) delivered to pork should render fresh pork trichina-safe.

A program has been initiated to assess the potential benefit from a cesium-137-based pork irradiation program. This program includes the following elements: (1) research to verify the radiation control of trichinae under conditions that simulate the modern pork industry; (2) a logistic and economic feasibility study of a large-scale pork irradiation program; and (3) development of a pork irradiation demonstration facility.

Introduction

The National Pork Producers Council (NPPC) Committee on Trichina-Safe Pork has recommended that the NPPC pursue a policy to provide a nationwide supply of trichina-safe pork by January 1, 1987. Irradiating pork to eradicate the trichina is one of the approaches identified by the Committee to accomplish this goal.

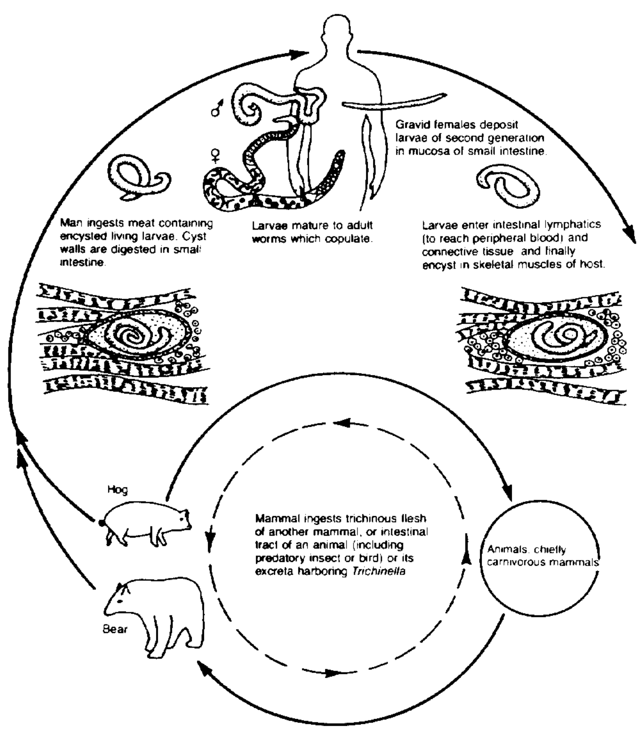
This paper presents the preliminary findings of studies to evaluate the feasibility of producing pork certified as "trichina safe" through the use of low-dose irradiation. The studies are being conducted as part of the Department of Energy, By-products Utilization Program (BUP). These studies include (1) research to verify the radiation control of trichina under conditions that simulate the modern pork industry, (2) a logistic and economic feasibility study of a large-scale pork irradiation program, and (3) development of a pork irradiation demonstration facility.

The Trichinosis Problem

Trichinosis is a parasitic disease caused by the microscopic nematode, *Trichinella spiralis*. The disease is found in numerous species of wild and domestic carnivorous animals, such as hogs, as well as in humans.

The life cycle of *Trichinella spiralis* is shown in Figure 1. When meat containing encysted trichina larvae is eaten, the muscle and cyst walls are digested, releasing the larvae. The free larvae quickly pass to the small intestine and burrow into the wall of the intestine where they mature and copulate in 2 to 4 days, producing a second generation of 1,000 or more larvae. Newborn larvae pass through the lymphatic and

Figure 1. The Trichinosis Cycle



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circulatory systems, eventually filtering throughout the body. Although the larvae attempt to penetrate all tissues and organs, they can only survive in the striated or voluntary muscles, such as legs or arms. Larvae within the muscle cells coil up, increase in size and become fully encysted 17 to 21 days after the initial infection occurred. The encysted parasites may remain alive in a dormant state for the life of the host (the normal course in human infection), or until the second-generation trichinous meat is again ingested by a carnivore.

The incidence of trichinosis in both humans and swine has declined dramatically in recent years. In 1947, when trichinosis became a reportable human disease, 451 cases and 14 deaths were reported. Over the 5-year period of 1976-1980, there was an average of 119 cases and 0.6 deaths per year (Center for Disease Control, 1982).

The types, sources, and methods of preparation of meat products incriminated as the source of trichinosis in 1981 have been summarized (Center for Disease Control, 1982). Of the 188 reported cases, pork products were incriminated in 146 (77%), 35 were from non-pork products and 7 were from unknown sources. Sausage was involved in 93 (49%) of the cases. Supermarkets, butcher shops or other commercial outlets were the source of meat in 101 cases (54%). Meat obtained directly from the farm was the source in 47 cases (25%). In 121 cases, the meat was not cooked. Many of these cases were from eating raw, smoked sausage.

Swine are usually infected from eating infected meat scraps in garbage that has not been properly cooked or from eating infected wildlife. Consequently, the incidence of the disease is substantially less in areas where hogs are grain-fed in confined areas, compared with those garbage-fed or that roam in woods or pastures.

The symptoms of trichinosis in humans depend in large part on the number of trichinae eaten. Eating a moderate amount of lightly infected raw or undercooked pork may result in no noticeable illness. However, eating even a small amount of heavily infected raw or undercooked pork may result in a serious case of trichinosis. If the infection is heavy, symptoms such as vomiting, diarrhea and abdominal pain may occur within 24 to 48 hours. However, these initial symptoms do not always occur.

The characteristic symptoms of trichinosis occur during the period when larvae are traveling through the body and becoming encysted in the muscle tissue. During this period, the symptoms include fever, edema, extreme muscular pain, petechial hemorrhage and eosinophilia. Permanent disability or death may occur with heavy infections. Treatments for trichinosis are directed toward relieving the distressing symptoms. There is no cure presently available for the disease.

Control of Trichinosis by Irradiation

A food sterilization program administered by the U.S. Atomic Energy Commission and the U.S. Army found that foods irradiated with high doses (10 to 60 kGy) were generally wholesome, although in some cases they were objectionable in flavor and aroma. Notably, pork and pork products were especially resistant to these effects and were deemed satisfactory, both aesthetically and nutritionally, even after doses of 30 kGy (Plough, et al., 1960). Wholesomeness and toxicity studies were also performed at lower doses up to 1 kGy (sufficient to inactivate trichinae) and, as expected, showed no detectable deleterious effects from radiation (Brownell, 1961). In fact, taste panel results in this work showed that such irradiated pork was preferable to the unirradiated samples, due to the extended shelf life of the former.

The literature indicates that when animals are fed irradiated meat containing encysted larvae, only very small radiation doses (5 to 10 Gy) are required to reduce the number of second-generation larvae able to encyst in the muscle tissue. A higher dose of 100 to 200 Gy sexually sterilizes the trichina larvae encysted in the irradiated meat, as evidenced by complete loss of infectivity in test animals (Alicata, 1951 and Gomberg and Gould, 1958). Microscopic examination of adult female trichinae developed from irradiated larvae reveals a complete degeneration of the reproductive system after these doses. At doses of 300 Gy, encysted larvae died in the enteric phase without reaching maturity. These results have also been confirmed by others (Gibbs, et al., 1958 and Taylor and Parfitt, 1959). Work currently underway by USDOE/USDA and their contractors irradiating infected market-weight split pork carcasses indicates that doses as low as 80 Gy provide sterility in first-generation larvae while 150 Gy prevents emergence of the encysted larvae.

Costs for pork irradiation facilities were developed by CH2M HILL (1983) for processing plants having a wide range of slaughter capacities. These costs are summarized in Table 1. The average cost in dollars per pound decreases from 0.0056 to 0.0016 as hog plant capacities expand from 1,000 to 10,000 hogs per day. In terms of dollars per hog, the average cost decreases from 0.954 to 0.271 over the same range of plant capacities.

Table 1 also shows how total average costs are partitioned into capital and O&M costs. Because capital costs are recovered in 4 years (25% ROI), the total average costs apply only to the first 4 years of plant operation. After that time, costs for irradiation are due to O&M only. Using a 4,000 hog-per-day plant as an example, irradiation costs would be about 39 cents per hog during the first 4 years of operation. Beginning the fifth year, irradiation costs would drop to about 10 cents per hog.

There are presently about 150 large-scale gamma (cobalt-60 and cesium-137) irradiators installed in the U.S., but none has yet been adapted to commercial hog processing facilities. Using standard radiation safety and control principles, however, the adaptation of current irradiator technology to commercial hog facilities is expected to be a matter of standard design practice.

In a current processing sequence in a hog slaughter facility, the live hogs are first stunned, exsanguinated and hung from an overhead conveyor for easy transferral throughout the plant. After dehairing, gutting, heading, splitting and cleaning, the prepared carcasses are placed in refrigerated storage for approximately 24 hours. The chilled carcasses are then ready for cutting, handling and packaging.

An irradiation facility could be designed to treat the pork at any of several stages in the processing sequence, such as after packaging or before dehairing. After passing through the facility, the pork could be processed as usual. The

Table 1. Pork Irradiator Cost Summary

	1,000 Hog/Day	*2,000 Hog/Day*	*4,000 Hog/Day*	*6,000 Hog/Day*	*8,000 Hog/Day*	*10,000 Hog/Day*
Capital Costs						
Facility Costs	$589,700	$634,800	$ 716,100	$ 806,700	$ 886,200	$ 964,500
Source Costs[a]	177,120	354,120	708,240	1,062,360	1,416,480	1,770,600
Subtotal Capital Cost	$766,820	$988,920	$1,424,340	$1,869,060	$2,302,680	$2,735,100
Annualized Cap. Cost (25% (ROI)	$191,705	$247,230	$ 356,085	$ 467,265	$ 575,670	$ 683,775
($/lb)[b]	0.0036	0.0023	0.0017	0.0015	0.0014	0.0013
($/hog)[b]	0.614	0.396	0.285	0.250	0.231	0.219
Annual Operating Costs						
Labor	$ 90,000	$ 90,000	$ 90,000	$ 90,000	$ 90,000	$ 90,000
Outside Services	3,000	3,000	3,000	3,000	3,000	3,000
Power	2,250	2,500	3,000	3,500	4,000	4,500
Source Recharge	5,810	11,060	21,550	32,450	42,970	53,470
Materials & Supplies	5,000	5,600	6,700	7,800	8,900	10,000
Subtotal Annual O&M	$106,060	$112,160	$ 124,250	$ 136,750	$ 148,870	$ 160,970
($/lb)[b]	0.0020	0.0011	0.0006	0.0004	0.0004	0.0003
($/hog)[b]	0.340	0.180	0.100	0.073	0.060	0.052
TOTAL ANNUAL COSTS	$297,765	$359,390	$ 480,335	$ 604,015	$ 724,540	$ 844,745
TOTAL AVERAGE COST[b]						
($/lb)	0.0056	0.0034	0.0023	0.0019	0.0017	0.0016
($/hog)	0.954	0.576	0.385	0.323	0.291	0.271

[a] Source used for estimate was the Cs-137 (WESF) capsule.
[b] Assumes a plant operating 6 days a week and 52 weeks per year, and assumes an average eviscerated weight of 170 pounds per hog.

irradiation facilities would not usually require significant amounts of floor space compared to the cutting and packaging floor.

Economic Impacts of Pork Irradiation

An analysis by CH2M HILL (1983) identified and assessed the likely impacts of pork irradiation on demand, prices and profits at producer, packer and retailer levels of the market channel. The anticipated effects on demand were examined by considering alternative scenarios, using plausible assumptions with respect to consumer and industry acceptance of irradiated pork. A summary of the economic analysis is given as follows:

- The trichinosis stigma causes pork demand to suffer in both the domestic and foreign markets.
- Irradiation is economically feasible if consumers react positively to trichina-safe pork.
- The irradiation of pork appears financially feasible, using a 25-percent rate of return on investment in the irradiation facilities. This rate of return is considered adequate to attract the funds necessary to finance the irradiation facilities.
- The contribution of irradiation processing to finished product unit cost is relatively small. Therefore, additional cost due to irradiation is not an overriding consideration in consumer acceptance. However, initial investment costs in irradiation facilities appear significant for packer/processors.
- There is a lack of conclusive evidence on consumer acceptance of irradiated pork at this stage of the research program. However, it appears plausible that trichinosis elimination would result in a 2-percent increase in the domestic demand for pork in the short run. In the long run, an additional 1-percent increase in domestic demand and an expansion of exports by one-third (or 1 percent of domestic production) appears plausible. On this

basis, industry profits would increase by a total of \$493 million per year in the short run, primarily as a result of increased prices. Economic theory suggests \$402 million would accrue at the farm level, \$74 million at the packer and processor level and \$17 million at the retail level. In reality, market power and other considerations could influence the share of the profits realized at the different levels.

- In the long run, the quantities of pork produced and handled would increase. Producer and packer/processor costs would increase accordingly and prices would change. The increased profits would decline to about \$30 million annually at the farm level, but would increase to about \$100 million at the packer/processor level.
- An analysis also was conducted of the economic impacts if consumers reacted negatively to the irradiation issue and domestic demand was reduced by 2 percent. Farm and retail sectors of the industry would suffer from reduced income but packer benefits exceed losses. In the short run, profits would decline by a total of \$393 million per year. In the long run, the decline would be \$7 million per year at the producer level. However, profits of \$38 million at the packer/processor level might be expected. This illustrates the importance of carefully evaluating and developing consumer acceptance.

Project Feasibility and Future Activities

The BUP (CH2M HILL, 1982) has determined that pork irradiation appears technically, economically and financially feasible. However, for a program to be successful, it must also be politically and socially feasible.

There do not appear to be any insurmountable obstables from the viewpoint of political feasibility. It appears likely that FDA will regard food irradiated at doses of 1 kGy or less as wholesome and safe for human consumption. The decision on whether the products must be labeled as "irradiated" may have an important influence on consumer acceptance.

There do not appear to be any insurmountable obstacles from the viewpoint of social feasibility. Detailed consumer acceptance studies should be undertaken if the required doses of irradiation have any discernible effects on the appearance, taste or texture of pork and pork products.

Although the prospects for pork irradiation are encouraging, several issues must be addressed in more detail before the pork industry makes the decision to implement such a technology. These issues include: (1) developing more conclusive evidence on consumer acceptance and preparing a consumer education plan, (2) developing reliable estimates of the demand for irradiated pork in both domestic and foreign markets, (3) operating a pilot plant to validate costs and engineering issues, (4) analyzing the economies of small-scale irradiators to serve small plants or to irradiate pork products presently treated for trichinosis at relatively high costs by refrigeration, (5) determining the adequacy of transportation facilities for increased exports, (6) confirming any potential benefits from reduced spoilage, (7) assessing other potential benefits and costs (such as from reduced use of additives), and (8) assessing packer/processor interest and developing an implementation program.

Several activities are being initiated through DOE's By-products Utilization Program to address these issues. They include organoleptic studies, consumer attitude surveys and construction of a demonstration pork irradiator.

Demonstration Facility for Pork Irradiation

It is important to demonstrate the feasibility of producing pork "certified trichina-safe" using existing gamma irradiation technology. Many design considerations for a pork irradiation facility are necessarily different from those for an irradiator used to disinfest citrus fruit or disinfect sewage sludge. Preliminary designs for a pork irradiator have dealt with the irradiation of the whole, slaughtered hogs. Unlike citrus fruit, the pork carcass is not geometrically symmetrical nor is it homogeneous like sewage sludge when irradiated. A demonstration facility would be designed to establish the optimum cesium-137 source configuration and arrangement to the materials-handling systems which could be used to expose the hog carcasses to a uniform dose from the source.

The economic importance of certifying pork "trichina-safe" by irradiation on a commercial scale in both domestic and international markets was discussed earlier. Reliable estimates of current capital costs for a demonstration irradiator have not as yet been fully developed, but are a significant factor in the economic analysis of the technology. A demonstration facility is needed to validate capital and operating costs for the irradiation treatment process.

The pork irradiation facility will be constructed at a state educational institution. This will ensure the availability of laboratory facilities necessary to provide a credible evaluation of irradiator design and of trichina disinfestation results. Participation in the program by the trade associations of the pork industry will be significant. The facility will be invaluable for research and development, as a site for technology observation by the industry and as an operator training and design refinement facility for subsequent irradiators constructed by and for the pork industry.

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