



REPORT OF A MISSION ON BEHALF OF THE WORLD HEALTH ORGANIZATION
TO THE NETHERLANDS AND THE UNITED KINGDOM FOR THE PURPOSE
OF LOOKING INTO THE POSSIBILITY OF IRRADIATION OF FEEDS

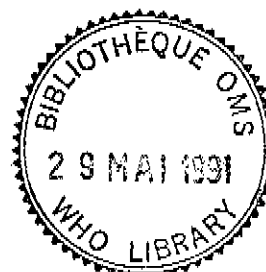
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1. Introduction

The World Health Organization is coordinating a number of activities on animal production hygiene. This has become a major component of the Zoonoses Programme and is being promoted through the Veterinary Public Health unit in cooperation with the Food and Agriculture Organization of the United Nations (FAO), the International Office of Epizootics (OIE) and the Interdisciplinary Working Party on Food Quality and Safety which represents an integrating initiative of the private sector (industries and consumers).

Following Resolution WHA42.40 of the World Health Assembly in 1989 on the prevention and control of salmonellosis, a number of working groups have been set up to deal with various aspects of research and harmonization of procedures. One of the questions dealt with by the working teams on salmonellosis control in agriculture concerned the production of pathogen-free feed, in particular for poultry. In principle, this can be achieved by proper acidification and heating during the pelleting process.^{1, 2} However, the risk of passing pathogens through feed to mass production of poultry should be completely avoided and therefore additional or alternative methods are to be investigated which sanitize the feed and retain its nutritional value.

The World Health Organization therefore requested Professor N. Skovgaard to investigate the potential of feed irradiation. Visits were made to irradiation plants engaged in irradiation of feed for laboratory animals and contacts were made to additional sources of information in Europe and North America. In view of the business interests of the irradiation plants, the addresses are not provided.

2. Pathogenic bacteria in feeds: need and possibilities for elimination by irradiation

Depending on the source of origin of the single components of concentrated feed, nearly all pathogenic bacteria may eventually be isolated from the mixed concentrate. In Table 1 a survey of some of the organisms is given, but the list might well include others.

¹ Report of WHO Consultation on Epidemiological Emergency in Poultry and Egg Salmonellosis, Geneva, March 1989 (Document WHO/CDS/VPH/89.82)

² Report of WHO Consultation on Salmonellosis Control in Agriculture, Orvieto, Italy, April 1990 (Document WHO/CDS/VPH/90.94)

TABLE 1: PATHOGENIC MICROORGANISMS OFTEN PRESENT IN FEEDS, AND THEIR POSSIBLE ELIMINATION BY IRRADIATION

Microorganisms which can be eliminated by irradiation:	Microorganisms which cannot be eliminated by irradiation:
<p>Salmonella species</p> <p>Yersinia enterocolitica</p> <p>Campylobacter coli/jejuni</p> <p>Aeromonas spp.</p> <p>Enteropathogenic E. coli</p> <p>Mycobacterium avium-intracellular complex</p> <p>Erysipelothrix rhusiopathiae</p> <p>"SPF" organisms in pigs:</p> <p>Mycoplasma spp.</p> <p>Actinobacillus spp.</p> <p>Pasteurella multocida/ Bordetella bronchiseptica</p> <p>Treponema hyodysenteriae</p>	<p>Clostridium perfringens type A & C</p> <p>Clostridium botulinum type A-F</p> <p>Bacillus anthracis</p> <p>Bacillus cereus</p> <p>Herpes virus</p>

It must be emphasized that some of the bacteria mentioned are ubiquitous in nature and will naturally be present in all feeds, dry or wet, e.g. vegetable crops. Feed concentrate does not necessarily play any particular role in the transmission from animals to man. For other bacteria listed it applies that their elimination from feeds is conditional for safe food production.

The most important organism with respect to this is, undoubtedly, salmonella. It is well documented that this organism can quite commonly be isolated from meat and bone meal, fish meal, soy meal, soy cakes, crushed soy, crushed rapeseed, rapeseed meal, cotton cakes, tapioca meal, etc.

Salmonella is an environmental bacterium in the processing of any kind of feed undergoing fat extraction or heat treatment, e.g. pelletizing. The predominant reason for contamination is condensation of air humidity during the cooling process, which makes it possible for salmonella to multiply in left-over dry cakes or dust. If contamination with salmonella is a problem in the production of certain feeds, such as pelletized concentrate, one has to find out where condensation may take place and the source of contamination will be found.

It is a misunderstanding to presume that pelletizing of feed makes it salmonella-free. The pelletizing process has not been implemented to kill bacteria, but merely to produce feed which is convenient for the farmer as well as for the animals. Unless certain minimum time/temperature levels are obtained in the pellets, and very strict rules are observed for the monitoring of this, and unless strict programmes also for the monitoring of critical control points on the production line are enforced, recontamination with salmonella will invariably take place. The monitoring programme should include regular

microbiological investigations for the presence of Enterobacteriaceae and salmonella in samples from the production line and the production environment. Relying on end-product examinations alone is not to be recommended.

It should be made quite clear that the pelletizing process itself is a very risky process with respect to continuous low-grade recontamination with salmonella of the final pellets, independent of the initial content of salmonella in the single compound of the feed concentrate.

The complicated nature of salmonella contamination of feed concentrates has been described in some detail above in order to explain that the production of salmonella-free feeds is not at all easy to achieve unless costly hygienic measures are taken.

In the CEC proposals for Council Regulations on the prevention of pathogens in feedstuffs are in the process of being accepted.³

These regulations would include:

- identifying and control of the critical points in processing
- carrying out microbiological control as further specified.

When the microbiological controls reveal that feedstuffs are contaminated with pathogens, the manufacturer shall:

- reprocess contaminated lots
- intensify the controls.

Ionizing irradiation offers a good alternative solution in making feed concentrate or pellets completely salmonella-free. The cost of this is low, and it can be done on a commercial scale without technical difficulties, as described below.

3. Radiation sources to be used for feeds

It was the unanimous opinion of two companies visited in Europe that the use of gamma rays for the irradiation of feeds is not feasible, considering the high throughput needed.

The present available technology, using ⁶⁰Co sources for irradiation, will be too costly to apply. At the current designed gamma plants it is difficult to handle the high volume needed for feed irradiation.

Gamma irradiation plants with a throughput of 100 000 tons per year have, however, been designed, including estimation of the cost as mentioned below.

The ⁶⁰Co source used for gamma irradiation is delivered in pens of approximately 10 000 Curie, the cost of which is in the range of US\$ 1 per Curie, equivalent to US\$ 10 000 per pen.

If one assumes that a 3 MCi (megaCurie) cobalt source is used, which is a very strong one, it has been calculated that this source would be able to irradiate 290 000 tons in one year (10 months), running 24 hours a day, if a

³ Anon. 1989. Proposal for a Council Regulation (EEC) laying down the veterinary rules for the disposal and processing of animal waste, for its placing on the market, and for the prevention of pathogens in feedstuffs. COM(89) 509 final. Brussels, 17 October 1989.

1 kGy dose is used. If 10 kGy is used, the throughput will be only 29 000 tons.

This calculation is realistically based on the fact that only some 25% of the emitted energy is absorbed by the product.

¹³⁷Cs irradiation sources are much less expensive than ⁶⁰Co. The cost is only approximately US\$ 0.20/Ci.

The lower cost of the ¹³⁷Cs is largely offset by the much higher source strength required to obtain the same throughput and by the lower dose distribution unfortunately obtained in a ¹³⁷Cs irradiator as compared to the gamma sources.

The overhead cost calculations show a clear cost benefit of electron beam irradiators as compared to either of the gamma sources used.

Assuming 100% efficiency, a 1 kW beam can irradiate 360 kg of product with a dose of 10 kGy in one hour. The efficiency of electron accelerators is higher than that of gamma sources because the electron beams can be directed at the product, whereas the gamma sources emit radiation in all directions. An efficiency of 50% is a realistic assumption for electron accelerator facilities.

In Odessa in USSR, two 20 kW accelerators, with an energy of 1.4 MeV, installed next to a grain elevator, came into operation in 1983. Each of these has the capacity to irradiate 200 tons of wheat per hour with a dose of 200 Gy (0.2 kGy) for the purpose of insect disinfestation. This corresponds to a beam utilization of 56%.⁴

A facility for electron irradiation of frozen deboned chicken meat commenced operation in Vannes, France, in 1986.

4. Doses needed for irradiation of feeds

The energy dose absorbed by the irradiated product is measured in Gray (Gy).

The Joint FAO/IAEA/WHO Expert Committee⁵ has concluded that the irradiation of any food commodity with an overall dose of up to 10 kGy presents no toxicological hazard; hence, toxicological testing of foods is no longer required.⁶

Irradiation of feed by the use of much higher doses may very well be toxicologically safe for animals, considering the relatively short lifespan of domestic animals for slaughter.

Movements for the protection of animals against cruelty are gaining an increasing importance in many countries, and purely ethical aspects of animal production are of growing interest to the consumer.

Hence, it serves no purpose to increase the irradiation doses of feeds beyond that adopted as safe for foods, and there is further no need for doing

⁴ Diehl, J. F. 1990. Safety of Irradiated Foods. Marcel Dekker, Basel.

⁵ Wholesomeness of irradiated food: Report of a joint FAO/IAEA/WHO Expert Committee. Technical Report Series 659. WHO, Geneva 1981.

⁶ Codex Alimentarius Commission. 1982. Report of a meeting of the Board of the ICFMH with participation of WHO, FAO, and IAEA. Copenhagen, 1982.

so, since the objective of the irradiation can very well be achieved by using overall doses of 10 kGy or less, as described below.

Large quantities of feed for experimental animals are already being sterilized by irradiation. The dose used for this purpose is 25 kGy or higher, which ensures sterilization of the product. In 1979 it was estimated in the UK alone that the total demand for laboratory animal feed was approximately 30 000 tons per year. Some 1 200 tons of this were sterilized by means of gamma radiation.

The use of doses in the range of 25 kGy is necessary only for feed for laboratory animals. It serves no purpose to use sterile feed for ordinary domestic animals, since they will be exposed to large quantities of bacteria, both from other dietary components than the concentrate, and from the environment. The feed concentrate needs only to be free from certain bacteria pathogenic to humans and which are known to be introduced into food via the feed-animal-food chain of contamination, salmonella being the most important of these. Freedom from this organism will at the same time guarantee freedom in the concentrate not only from a number of other human pathogenic bacteria, but also from many of the organisms responsible for animal diseases only. Virus causing diseases such as swine fever and Aujeszky's disease are important exceptions from this (see Table 1).

The number of enteropathogenic bacteria, even in the most contaminated feed ingredients, tends to be low, seldom exceeding 1/g.

D-values for enteropathogenic bacteria such as salmonella, yersinia, campylobacter in ground beef have been demonstrated to be in the order of 0.55-0.78 kGy, 0.1-0.2 kGy, and 0.15-0.20 kGy, respectively; and a dose as low as 1 kGy will reduce the number of salmonella with a factor 20-65.

Doses in the order of 10 kGy will certainly make concentrated feeds safe from enteropathogenic microorganisms, apart from sporeformers and virus, with a wide safety margin.

For commercial sterilization of feeds it is therefore recommended not to use doses higher than 10 kGy, and even doses in the range of 5 kGy will in some cases be sufficient.

Not to exceed 10 kGy has a positive effect on the cost; and any discussion of an emotional nature related to animal welfare, caused by the theoretical possibility that doses higher than 10 kGy may have carcinogenic or mutagenic effects on the animals, will be avoided.

5. Irradiation: economic considerations

5.1 Introduction

The cost of irradiation of food is a critical factor in its application. How much extra are the consumers prepared to pay for the safety of their food? What priority does society give to ensuring that food is safe, e.g. with respect to salmonella?

Sweden is enforcing extremely rigorous rules to exclude salmonella from poultry. The requirements for freedom from salmonella in the various poultry feed components are very strict, and likewise the requirements for the hatcheries and the broiler production. Extermination of infected flocks and condemnation of contaminated slaughtered broilers is practised; and freedom from salmonella in imported poultry is a requirement. This is costly.

Quite recently a lot of Swedish poultry was imported to Denmark and retailed with the guarantee of being salmonella-free. The price of the Swedish poultry was more than three times higher than the price of locally produced Danish poultry which may possibly harbour salmonella. The high price of the Swedish poultry is due to the strict rules enforced to eliminate salmonella. Most countries, if not all, would be able to eliminate salmonella from poultry if the retail price of the product could be tripled.

When evaluating the cost of irradiation of feed concentrates, a number of factors must be considered. First of all, whether it is possible to irradiate the feed concentrate considering the large quantities involved. This evaluation requires an analysis of the total consumption of feed concentrate by the individual animal species, either over a lifespan (poultry and pigs) or per year (cattle). Further information is needed on the cost of the concentrate as well as the additional cost of the irradiation process and the impact of this on the prices of the final product, the meat.

In this context it is necessary also to evaluate the doses needed to eliminate pathogens from feeds which may enter into the food chain, because high dose levels are more costly than low doses.

Another factor which must be considered is the necessity to irradiate feeds used for the various animal species in order to prevent transmission of zoonotic agents from animals to man. Is feed of importance at all in this respect, is it of only minor importance, or is it one of the major sources of transmission?

5.2 Cost of gamma processing of feed concentrate

A company in North America had by the end of August 1990 calculated the cost of gamma processing of animal feed for a single facility with a throughput range of 70 000-100 000 tons per year, using an overall average dose of either 5 kGy or 10 kGy, as follows:

The performance of an irradiator is normally calculated on the basis of a minimum applied dose. Therefore, these average doses must be converted into D_{min} 's. Applying the Codex Standard as a guide and the assumed product density of 0.4 to 0.5 g/cc, the average doses (D_{av}) correspond to:

$D_{av} = 5 \text{ kGy} \dots\dots\dots D_{min} = 3.5 \text{ kGy}$
 $D_{av} = 10 \text{ kGy} \dots\dots\dots D_{min} = 7.0 \text{ kGy}$

This conversion is based on the anticipated overdosing ratio of 1.8 (D_{max}/D_{min}).

Facility operation

The same company in North America anticipates that the irradiation facility will become part of an existing manufacturing plant. It would operate on the basis of 8 000 hours per year. Some additional staff (up to three) would have to be hired to supplement the existing work force of the plant.

Calculations of the Unit Processing Cost have taken into account three major components:

- investment capital,
- depreciated capital,
- annual operating costs.

A summary of the Unit Processing Cost (UPC), based on the above, is presented in the following table:

Throughput (tons/ year)	Average dose (kGy)	Investment capital (\$ 000)	Depreciated capital (\$ 000)	Operating costs (\$ 000)	UPC (\$/ton)
70 000	5.0	2 599.17	134.55	459.69	8.49
	10.0	5 198.30	135.53	779.39	13.07
100 000	5.0	3 713.10	134.94	596.71	7.32
	10.0	7 426.20	136.41	1 053.42	11.90

Notes:

- 1) The above figures are in 1991 Canadian dollars
- 2) One ton = 1 000 kg
- 3) Accuracy of above estimates are within \pm 20%
- 4) Investment capital excludes cost of land.

The unit processing costs of Can\$ 7.32 and 11.9 per ton for irradiation of 100 000 tons per year, using an average dose of 5.0 and 10 kGy, correspond to US\$ 6.24 and 10.14 respectively, per ton, according to the ultimo 1990 rate of exchange. This corresponds to US\$ 0.0067 and 0.01 per kg feed.

5.3 Increase in prices of poultry feed by irradiation

The price increase for the 3 kg of irradiated feed used for feeding a broiler, will vary greatly according to the market prices of feed. In parts of Europe the prices of poultry feed vary from US\$ 300 to 350 per ton. Using an irradiation dose of 10 kGy will increase the feed prices to US\$ 310-360 per ton, or by approximately 3%.

5.4 Increase in prices of poultry meat by using irradiated feed

A broiler, having a slaughtered weight of approximately 1 kg, consumes a total of 3 kg feed concentrate. The extra cost of irradiating the feed to eliminate salmonella and campylobacter for example can thus be calculated to correspond to US\$ 0.019 and 0.030 per broiler, by use of doses of 5 and 10 kGy, respectively.

How much the use of irradiated feeds will increase the retail prices of broilers will, of course, vary according to the local market price of poultry meat. Anticipating a retail price for broilers of US\$ 3-4 per kg, a conservative estimate would be that irradiation of the feed to an average dose of 10 kGy would increase the price per poultry carcass by approximately 0.5-1%.

5.5 Cost of electron beam processing of animal feed

One firm in Europe estimates the following cost based on a required throughput of 100 000 tons per year, and assuming a product density of around 0.65, a product conveyor 1 m wide, operating at 6.6 m per minute, and double-shifting the electron beam facility over five working days per week, suggesting two 10 MeV 40 kW machines operating within a dual product time. A budgetary quotation for this type of machine is approximately GBf 1 800 000-1 900 000.

This quotation does not allow for product handling equipment nor the facility building, typical costs of which would be GBf 250 000-300 000 and GBf 1 000 000 per unit, respectively.

The overall figures, including electron beam facilities, product handling equipment, and facility building, will thus be in the order of GBf 3 000 000-3 200 000.

Using the highest estimate, GBf 3 200 000, this will correspond to US\$ 6 300 000 per 100 000 tons, or US\$ 0.063 per kg, or US\$ 0.19 per broiler consuming 3 kg feed concentrate and having a slaughtered weight of about 1 kg. This will correspond to an increase of retail prices by 6%, using the same retail price per broiler as above.

Another firm in Europe has given the following information. A first full-scale commercial facility using electron beams for the treatment of food was started in Ashkelon, Israel, eight years ago. This facility was constructed to radicize poultry feed and was a joint project between a company in Israel in cooperation with the Israel/United States Binational Industrial Research and Development Foundation (BIRD-F).

The whole study exists, including of course all peripheral equipment to optimise the process efficiently. Based on this, the following calculations for a plant having a capacity of 100 000 tons per year, can be made.

Production capacity:

If we use these figures for calculation, this should lead to the following:

- Dose (D): 10 kGy
- Yearly throughput: 100 000 tons
- Machine characteristics: V = 1.5 MeV; I = 75 mA
- Amount of beam effectively used in the product (E): conservatively 50%
- Hourly production capacity (C) formula in kg/h:

$$C = \frac{3\ 600\ V \times I}{D} \times E = C = 20\ 250\ \text{kg/h}$$

If we consider a 100 000 tons spread quite homogeneously over a one-year period, the machine would have to run approximately 5 000 hours per year. This is a conservative figure, knowing that this type of machine (I.C.T.) can run 24 hours a day with very little maintenance. Some machines have not been opened for six years of work.

Economics

The capital investment for the electron beam system is US\$ 1 150 000 for the machine itself plus the auxiliary equipment.

The auxiliary equipment includes a gas handling system, 1 550 kg of SF₆ insulating gas, an under-beam handling system, and the shielding usually made of concrete. These costs range from US\$ 200 000 to 500 000 depending on the sophistication of the under-beam handling and the size of the associated shielding.

Installation and start-up costs usually amount to US\$ 150 000 or less, depending on customer's site preparation.

Operating costs include a part-time equipment operator, some facilities such as water and electricity, and maintenance. They can be evaluated to US\$ 20 per hour.

Cost summary

Depreciation schedules for capital investments and treatment of investment tax credits on these costs vary with specific accounting policies. However, typical capital investment amortization and interest costs run in the range of US\$ 30-80 per hour. Operating costs add a further US\$ 10-20 to these costs. The economics of Electron Beam Processing are most favourable for multi-shift continuous processes.

The overall cost per hour thus amounts to approximately US\$ 80 + 20 = US\$ 100 per hour. With a throughput of 100 000 tons/year and a running time of 5 000 hours/year, corresponding to 20 tons/hour, the cost for irradiation of 1 ton of feed will be 100/20 = US\$ 5 per ton, equivalent to US\$ 0.005 per kg. Presuming the same prices of poultry meat as given above under cost of gamma irradiation of animal feed, the price increase will be insignificant, in the order of less than 0.5% per kg poultry meat.

Calculations on the cost of irradiation of meat- and bone meal

The Danish Meat Research Institute in Roskilde has investigated the cost of establishing an irradiation plant with a capacity of 140 000 tons/year based on the use of an electron beam processing plant in North America and applying an overall dose of 10 kGy.

Total establishing costs

A 4.0 MeV/50 mA Dynamitron, 200 kW, including buildings:	Dkr. 33 000 000
Interest and depreciation (12% per year/7 years):	<u>Dkr. 0.048/kg</u>

Running costs per year

Electricity (500 kW, 400 hours/year):	Dkr. 800 000
Maintenance (Dkr. 150/hour, 400 hours/year):	Dkr. 600 000
Labour costs (1 ^{1/2} man/shift, 2 shifts):	Dkr. 600 000
<u>Running costs per year, total:</u>	<u>Dkr. 200 000</u>
- equivalent to:	<u>Dkr. 0.014/kg</u>

Total expenditures Dkr. 0.062/kg when handling 140 000 t/year and using 10 kGy - Dkr. 62/ton = approximately US\$ 11/ton.

5.6 Feasibility of irradiation of feed concentrate for pigs and cattle

Concentrate for pigs

Pigs are fed both coarse fodder and concentrate. The use of concentrate in the total diet varies enormously according to the animal husbandry tradition and the infra-structure of the farming.

It is, however, not unusual to feed a pig which is slaughtered at a live bodyweight of 90 kg, a total of 250-300 kg concentrate.

The cost of irradiation of 1 ton of poultry feed was estimated (above) to be approximately US\$ 10. The cost of irradiation of the total quantity of concentrate fed to a pig of 90 kg will then be approximately US\$ 2.50-3.00 when using 250-300 kg concentrate.

As was the case with poultry feed, the prices of concentrate used for pigs vary quite a lot but may in some areas of Europe be within the range of US\$ 250-300 per ton, corresponding to approximately US\$ 60-75 per pig with a live weight

of 90 kg. The extra cost of US\$ 2.50-3.00 per pig when using irradiated concentrate, will thus increase the price by approximately 3-4%.

This increase in the cost of the feed per pig must be compared with the total value of the carcass and organs. This can be estimated to be in the range of US\$ 130-150; naturally subject to considerable variation. The extra cost of approximately US\$ 3 per pig, when using irradiated concentrate only, will increase the price of the pork by approximately 2% or correspondingly reduce the income of the farmer.

Many farmers use home-produced concentrates, e.g. barley, wheat, maize, etc., to a large extent. Such feeds can be considered to be safe from pathogenic bacteria such as salmonella and need not be irradiated, thus reducing the cost of irradiation of concentrate for pigs to a very low level. The same will, of course, apply to poultry feed when farmers use home-produced grain in addition to concentrate bought at feed mills.

It is not necessary to recommend irradiation of all concentrate for pigs. On the other hand, it must be recommended that supplementary concentrate containing meat- and bone meal, fish meal, soy cakes, and similar components which are well known to constitute a salmonella risk, is decontaminated, e.g. by irradiation. The cost of this per pig will be low and it will be more than balanced by a reduced prevalence of faecal excreters among pigs for slaughter. This prevalence is known to be as high as 30-40% of the pigs in some countries, resulting in well over half of the samples of raw minced pork being salmonella positive.

Concentrate for cattle

The use of concentrate for cattle varies from 0 to 2-3 kg per day for a high-yield lactating cow. The use of 1 500 kg concentrate per head of cattle per year is not uncommon. The estimated cost of this is given in the above section about concentrate for pigs.

Many of the sub-components used in concentrate for cattle may be even heavily contaminated with salmonella. This applies particularly to compounds such as cotton cakes and any other kind of cakes resulting from fat extraction processes, e.g. soy cakes.

It must be remembered that salmonellosis in cattle, or faecal excreters amongst cattle for slaughter, is not to the same extent a feed problem as is the case with pigs and poultry. Good animal husbandry is the predominant factor, e.g. the eradication of *S. dublin* in herds suffering from infection, eradication of *S. typhimurium* in calves, prevention of *S. typhimurium* spread during transport of calves to slaughter or to market, etc.

6. Nutritional aspects of feed irradiation

Chemical analyses and animal feeding studies have shown that the nutritional value of proteins is but little affected by irradiation even at high doses. Animal studies in various species have also demonstrated a minimal effect of irradiation on other nutrients.⁷

The main concern when using compounded irradiated feed concentrates, either as pellets or as meal, is whether loss of vitamins has taken place. Some

⁷ Food Irradiation. A Technique for Preserving and Improving the Safety of Food (WHO, 1988).

vitamins, such as riboflavin, niacin, and vitamin D, are fairly insensitive to irradiation. Others, such as vitamins A, B₁, E, and K, are more easily destroyed. There are conflicting results concerning the effects of irradiation on vitamin C in vegetables, but this is less important in animal feeds because some of the domestic animals synthesize vitamin C themselves. Fairly large quantities of feed for experimental animals are being irradiated at doses of 25 kGy and higher, without any reported harmful effects on the animals.

The absence of any deleterious effects of irradiation of poultry feeds, as well as the wholesomeness of radacidized feed, have been demonstrated in the UK, Canada and the Netherlands. ⁶

Broilers are to a large extent produced exclusively by feed concentrate either as meal or as pellets. Irradiation of the total diet for poultry is quite feasible from a practical as well as from an economical point of view, as described above. The quoted information on the non-adverse effect on poultry by using irradiated feed, thus becomes very important.

When it comes to feed concentrates for cattle and pigs, this will constitute only a minor portion of the total feed consumption, and any possible reduction of the nutritional value of the feed, caused by irradiation, will be of no importance.

7. Use of organic acids as an alternative to irradiation

It is a well established fact that certain organic acids, e.g. propionic acid and acetic acid, have a killing effect on salmonella.

To ensure salmonella-free feed, however, the acid must be admixed in concentrations of no less than 3-4%. This has been observed to be very corrosive for the equipment and also to cause environmental problems. Furthermore, it is rather expensive. The cost of admixing 3% propionic acid is in the order of US\$ 3-4 per 100 kg feed, the price of 1 kg of propionic acid being approximately US\$ 1.00.

However promising the use of organic acids has seemed from a theoretical point of view, it has turned out in practice to be far too costly in the decontamination of feeds for salmonella, and also to present practical problems which are difficult to solve.

8. Conclusions

1. A joint WHO/IAEA/FAO Expert Committee has concluded that the irradiation of any food commodity up to an overall dose of 10 kGy presents no toxicological hazards. This dose is sufficient to achieve the objective of making feed given to meat-producing animals safe from zoonotic microorganisms such as salmonella and campylobacter. Even lower doses, e.g. 5 kGy, may in many cases be adequate.
2. Plants intended for the irradiation of feeds need to be large-scale as compared with those used for food, having a capacity of 100 000 tons or more per year.

⁶ Lapidot, M. 1979. Radacidation and radappertization of animal feeds in Israel, 1968-1977. Panel Proceedings Series, Decontamination of Animal Feeds by Irradiation. IAEA, Vienna, 1979.

The technology for this is readily available, whether gamma irradiation or accelerated electron beams are to be used.

3. Both gamma irradiation and accelerated electron beams can be used for decontamination of feeds.

However, the general opinion against any use of radioactive materials is in favour of the use of accelerated electron beam plants. When such plants are not in operation, the radiation sources are simply stopped; furthermore, there is no problem with radioactive waste materials or replacement of gamma irradiation pens.

4. The cost of gamma irradiation has been estimated by a company in North America to be approximately US\$ 10 for irradiation of 1 ton of feed with an overall dose of 10 kGy. If only 5 kGy is used, the cost will be approximately US\$ 6.
5. The cost of accelerated electron beam irradiation of feed has been calculated by a company in Europe to be approximately US\$ 5 per ton.
6. A survey made by the Danish Meat Research Institute on the cost of irradiation of meat- and bone meal, using an electron beam plant with a capacity of 140 000 tons per year, constructed by a North American company and applying 10 kGy, shows that the cost will be only approximately US\$ 2.50 per ton.
7. Depreciation schedules for capital investments and treatments of invested tax credits are subject to worldwide variation. However, it seems fair to state that a conservative estimate of the overall cost of irradiation will be within the range of US\$ 5-10 per ton of feed.
8. How much the price increase percentage for irradiated feeds will be is difficult to estimate, and will vary according to local feed prices. The price of concentrated feed for poultry is in parts of Europe within the range of US\$ 300-350 per ton. The irradiation cost will add up to US\$ 10 to this, i.e. to US\$ 310-360, or approximately 3%.
9. Using the above indicated prices of poultry feed as the basis for calculation, then the price of one broiler, weight approximately 1 kg and having consumed approximately 3 kg feed, will increase by only a few US\$ cents.
10. The prices charged at present for gamma irradiation of foods in Europe are in the range of US\$ 100-300, depending on the dose density, frequency, and utilization frequency; much higher than the corresponding prices for feeds.
11. With respect to the nutritional value of irradiated feed, no investigation on the use of such feed to poultry has been able to demonstrate any adverse effect of irradiation with 25 kGy. It is, however, not necessary to use larger doses than 5-10 kGy to achieve the purpose: salmonella-free feed.
12. Large quantities of feeds for experimental animals, as well as dry pet food, e.g. for dogs and cats, are sterilized by means of irradiation doses of 25 kGy or higher. No adverse effect of this has so far been reported in literature.
13. Concentrate for cattle and pigs make up only a minor part of the total diet, and any loss in the nutritional value of the feed, e.g. loss in the vitamin contents, will - for that reason alone - be of no importance.

14. With respect to concentrate fed to pigs, it seems more feasible to irradiate the contaminated components of the feed, e.g. meat- and bone meal and fish meal, rather than the final feed mix or pellets.
 15. Pelletizing of feed cannot be relied on as a means of making it free of salmonella, unless extremely strict good hygienic manufacturing practice is observed, including constant monitoring of the critical control points according to the HACCP concept.
 16. Admixture of organic acids, e.g. propionic acid, to feed concentrates, has turned out to be inadequate for the total elimination of salmonella from feed. The concentrations needed to achieve this purpose are too costly, and the acids used are furthermore highly corrosive for the equipment as well as constituting environmental health problems for the labourers.
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