Mixed feed and its ingredients electron beam decontamination

V V Bezuglov, A A Bryazgin, A Yu Vlasov, L A Voronin, Yu V Ites, M V Korobeynikov, S V Leonov, M A Leonova, V O Tkachenko, E A Shtarklev and Yu G Yuskov

1Budker Institute of Nuclear Physics SB RAS, Lavrentieva, 11, 630090 Novosibirsk, Russia
2Institute of Experimental Veterinary of Siberia and Far East SB RAS, 630501 Krasnoobsk, Novosibirsk region, Russia
3Novosibirsk National State Research University, Pirogova, 2, 630090 Novosibirsk, Russia
E-mail: M.V.Korobeynikov@inp.nsk.su

Abstract. Electron beam treatment is used for food processing for decades to prevent or minimize food losses and prolong storage time. This process is also named cold pasteurization. Mixed feed ingredients supplied in Russia regularly occur to be contaminated. To reduce contamination level the contaminated mixed feed ingredients samples were treated by electron beam with doses from 2 to 12 kGy. The contamination levels were decreased to the level that ensuring storage time up to 1 year.

1. Introduction

Russia has the vast areas with cold severe climate. The goods are delivered to the people living and working in these Northern Territories only during summer. The poultry factories are also supplied with mixed feed only in summer time, and the decontamination of the mixed feed will decrease the feed losses during the year.

Mixed feed ingredients supplied in Russia regularly occur to be contaminated. The main problems are caused by fish flour and soya. The fish flour is produced on the ship far away in the ocean and then pass the long way to the final consumers by ships and then more than 5 thousand kilometers by train and often by river boats. Contaminated soya is supplied from Far East and its way is on trains and river boats and barges.

When the train (tens of wagons) or barge with mixed feed ingredients arrived to poultry factory the products are assayed. The bacterial contamination tests last 2 weeks, and only after that ingredients can be used for mixed feed preparation. If the test results show that contamination level exceeds the admissible limits there is no way to send the products back to seller – too long and too expensive way back, or no possibility to deliver back because of short navigation period on northern rivers.

So usually the poultry farm officials have choice of 3 possibilities – to discard the contaminated ingredients, to “dilute” contaminated ingredient by not contaminated components to decrease contamination level to admissible values (rarely happening possibility) or to put it in production and to add great amount of antibiotic preparations into mixed feed to prevent poultry loss. The antibiotics prevent poultry losses but accumulate in poultry meat, and it will not meet sanitary requirements – again financial losses. The contaminated mixed feed can contaminate feed kitchen, and it will be hard to make it contamination free.
Thermal treatment is not suitable to reduce contamination level because it will spoil the ingredients’ nutritional properties.

Electron beam treatment can be the problem solution – it reduces the contamination level without heating (so it is also named “cold pasteurization”) and without spoiling nutritional properties.

The radiation sterilizing abilities were discovered in the beginning of XXth century. First patent describing radiation usage for food preservation is dated July 17 1930 [1].

The radiation treatment of food really started in the end of 40-s in XX century. Food irradiation became normal practice in the end of XXth century due to technical development of electron accelerators, increase of their energy and beam power resulting also in irradiation cost decrease and welfare growth – all these factors make the food radiation treatment economically viable process.

Accelerators development and radiation technologies are described in [2]. Electron beam treatment is used for food products to prevent spoiling and prolong the storage time. Main facts about food irradiation and research results are given in [3-7]. Food irradiation practices are described in [8-13].

Budker Institute of Nuclear Physics (BINP) is one of the world leaders in accelerator development and production [2]. More than 140 industrial electron accelerators were supplied and installed by BINP all over the world.

2 electron accelerators produced by BINP were installed in 1982 in Odessa port elevator to decontaminate the wheat imported from Canada if the contamination levels exceed admissible values. Later 2 electron accelerators produced by BINP were installed in port elevator in Guangdong province.

We have not find information that anyone used electron beam treatment for decontamination of mixed feed or its ingredients. We have carried out research work to estimate the possibilities of electron beam treatment for mixed feed ingredients processing. It was assumed that it is better to treat the ingredients with high contamination level than ready mixed feed.

The main aim of the work was to determine the minimal dose allowing to prevent the mixed feed from spoiling during the transportation to the Northern Territories and following storage during the period up to the year – till the next year navigation. The second aim was to estimate nutrition properties degradation after electron beam treatment.

2. Experimental
A pulse radio frequency electron accelerator ILU-6 installed in BINP is used for experimental works – development of radiation technologies and development of accelerator systems. Many radiation technologies were elaborated on this machine.
Numerous researches have shown that the pulse electron beam better suppresses microflora than continuous electron beam due to higher impact during the pulse. [14-18]

Figure 1 shows dose-depth curve for electron beam treatment. Beam penetration ability $R_{opt}$ at energy of 2.5 MeV is 0.8 g/cm$^2$.

![Figure 1. Dose-depth curve for electron beam treatment.](image-url)
ILU-6 parameters are listed below:

- Electron energy – up 2.4 MeV
- Pulse beam current – up to 420 mA
- Pulse duration – 0.5 ms
- Pulse repetition rate – up to 50 Hz
- Scanning width – 90 cm
- Sample table underbeam transportation velocity – up to 8 cm/s

Electron beam and X-rays generate free radicals and, in the presence of water, a constituent of all living matter, highly reactive short-lived hydroxyl radicals. Both can lead to single and double-strand breaks, intra-strand cross-links and thus damage DNA, including breaking the hydrogen bonding between the nucleotides in the dyad. With but a few double strand breaks, DNA is no longer able to repair or replicate itself. Without the ability to correctly replicate their own DNA structure, cells die. Pathogens in food or on medical products exposed to sufficient ionizing radiation are then died and bio-burdens eliminated [2].

The more complicated is the organism the less is the lethal dose. Simplest microbes (especially in spore form) and mold fungi possess highest resistance to irradiation.

Typical doses for various irradiation processes:
- Sprouting inhibition 0.1 – 0.2 kGy
- Disinsection 0.3 – 0.5 kGy
- Parasites development inhibition 0.3 – 0.5 kGy
- Fruits maturing delay 0.5 – 1.0 kGy
- Fungi inhibition 1.5 – 3.0 kGy
- Bacteria inhibition 1.5 – 3.0 kGy
- Sterilization 15 – 30 kGy
- Polymerization 25 – 50 kGy

For most bacteria the dose of 2 kGy is so called $D_{10}$ – the dose that results in 10 times reduction in survived bacterial population. So we have taken 2 kGy as minimal dose and dose step.

3. Electron beam treatment of packed samples and its results

The mixed feed and its ingredients samples were subjected to electron beam treatment by ILU-6 pulse electron accelerator. Electron beam treatment parameters were:

- Electron energy – 2.4 MeV
- Beam penetration ability – 0.8 g/cm$^2$
- Pulse beam current – 320 mA
- Pulse duration – 0.5 ms
- Pulse repetition rate – 5 Hz
- Scanning width – 90 cm
- Underbeam transportation velocity – 2 cm/s

Treatment doses in out experiments varied from 2 to 12 kGy.

In experiments we use the feed contaminated by coliform (1.5*10$^6$ cfu/g), spore forms (1.2*10$^6$ cfu/g) with total bacterial count of 3.0*10$^6$. The study of microbial contamination of feed samples was carried out by methods provided by state regulations of Russia (GOST 51426-99, ISO 7251-2005, ISO 7218-2008, ISO 11133-1-2008) for microbiological testing of feed.

The mixed feed samples were placed into the hermetically sealed packs. The packs with the mixed feed were placed on the moving table and were transported under the electron beam that was scanning across the table moving direction overlapping all table surface.

Figure 2 shows the moving table with the mixed feed samples and its 9 ingredients inside the packs. The treatment doses varied from 2 to 12 kGy. The packing was done so that the product mass thickness was about 0.3-0.4 g/cm$^2$ that is 2-3 times less than electron beam penetration depth $R_{opt}$ at energy of 2.4 MeV that nearly equal to 0.8 g/cm$^2$ to ensure good dose uniformity.
Figure 2. Samples of mixed feed and of its ingredients on moving table prepared for electron beam treatment.

Treated samples were tested using the standard microbiological technique. The usual and selective mediums were used for incubation during 24 hours at temperature of 37°C. The bacterial colonies amount, rates of coliforms and spores were counted.

Total microbial count was reduced to an acceptable concentration after electron beam treatment with doses of 4 kGy and higher.

Coliforms were not fixed after EB treatment with the dose of 12 kGy.

The spore forms of micro-organisms survive after treatment dose of 12 kGy.

Figure 2 represents the treatment results. The diagram shows amount of colony-forming units per gram dependence on the treatment doses. Red line is the legal limit that is allowed in poultry feed in Russians Federation – $5 \times 10^5$ cfu/g. Coliform bacteria are not allowed in poultry feed.

Figure 3. Electron beam treatment results - amount of colony-forming units per gram dependence on treatment doses.
4. Conclusion
Total microbial burden in mixed feed and its ingredients samples was reduced to an acceptable level after electron beam treatment with doses of 4 kGy and higher.

Coliforms were not fixed after EB treatment with the dose of 12 kGy.

The spore forms of micro-organisms survive after dose of 12 kGy.

The EB treatment can decrease the mixed feed losses and prolong the storage time. This method can be potentially applicable for treatment of mixed food lots with contamination level exceeding the admissible values.

References
[1] Wüs O 1930 Procédé pour la conservation d'aliments en tous genres Brevet d'invention 701302 (July 17)
[2] Industrial radiation Processing With Electron beams and X-rays, 2011. International Atomic energy Agency technical document, http://www.cirms.org/pdf/Industrial%20Radiation%20Processing%20-20May%202011%20-%20Revi sion%20.pdf
[3] Facts about food irradiation. Document of Food and Environmental Protection Section. Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, http://wayback.archive.org/web/20060316042916/http://www.iaea.org/programmes/nafa/d5/p ublic/foodirradiation.pdf
[4] GAO, Food Irradiation: Available Research Indicates That Benefits Outweigh Risks, GAO/RCED-00- 217 (Washington, D.C.: Aug. 24, 2000). http://www.gao.gov/archive/2000/rc00217.pdf
[5] GAO-10-309R Federal Oversight of Food Irradiation http://www.gao.gov/assets/100/96545.pdf
[6] Food Safety News/ Texas Researchers Devise New Irradiation Method http://www.foodsafetynews.com/2010/12/texas-researchers-devise-new-irradiation-method/
[7] Irradiated food/ Global development&Irradiation as a quarantine treatment Irradiation technology industrial application forum 19-20 july 2011 http://www.latu.org.uy/docs/7-Carl-Blackburn-Alimentos-irradiados-medida-cuarentenaria.pdf
[8] ASTM F1355 - 06(2014) Standard Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment
[9] ASTM F1356 - 08 Standard Practice for Irradiation of Fresh and Frozen Red Meat and Poultry to Control Pathogens and Other Microorganisms
[10] ASTM F1736 - 09(2016) Standard Guide for Irradiation of Finfish and Aquatic Invertebrates Used as Food to Control Pathogens and Spoilage Microorganisms
[11] ASTM F1885 - 04(2010) Standard Guide for Irradiation of Dried Spices, Herbs, and Vegetable Seasonings to Control Pathogens and Other Microorganisms
[12] ASTM E2449-05(2013) Standard Guide for Irradiation of Pre-packaged Processed Meat and Poultry Products to Control Pathogens and Other Microorganisms
[13] ASTM F1640 - 09 Standard Guide for Packaging Materials for Foods to Be Irradiated
[14] Tallentire A, Purdie J W and Ebert M 1974 Increased response of anoxic Bacillus megaterium spores to radiation at high dose-rates International Journal of Radiation Biology 26 5 435-443
[15] Tallentire A and Barber D J W 1978 The interrelationship between Pulse Length and Dose-rate within the Pulse in the Enhancement of Atomic Damage in Wet Bacillus megaterium Spores Irradiated with Pulses of Electrons. Sixth Symposium on Microdosimetry (Booz and Ebert, edt.). Harwood Academic Publishers Ltd. 1061-1069
[16] Barber D J W and Tallentire A 1980 Modification by Chemical and Physical Means of the Pulse Dose Effect in Irradiated Bacteria Spores. Seventh Symposium on Microdosimetry (Booz, Ebert and Hartford, edt.). Harwood Academic Publishers Ltd. 1145-1155
[17] Tallentire A 1983 Oxygen effect, hydrogen peroxide yields, and time scale of interation of potentially damaging species in electron pulse irradiated bacterial spores Advances in space
[18] DeVaux L C, et al. Effect of Electron Beam Dose Rate on Microbial Survival. Proceedings AccApp '07, Pocatello, ID (July 29 – August 2, 2007) 388-393