THE USE OF HIGH-ENERGY ELECTRONS AND X-RAYS FOR THE PRESERVATION OF MEAT AND OTHER FOOD PRODUCTS

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ABSTRACT

The introduction of irradiation processes for the preservation of food will be strongly influenced by considerations of reliability, economy and safety. The practicability of on-line radiation processing has already been amply demonstrated in other industries for curing plastic and rubber goods, crosslinking the insulation on electrical wire and cable, and sterilizing disposable medical devices.

This paper reviews the technical feasibility and cost of treating meat and other food products with high-energy electrons and x-rays generated by high-voltage electrical equipment. Electron beams are applicable to small packages processed at high thruput rates. X-rays are applicable to larger packages at lower rates. These techniques provide alternatives to the use of large radioactive sources for the preservation of food.

INDUSTRIAL IRRADIATION PROCESSES

The availability of reliable, high-power electron accelerators is stimulating the use of ionizing radiation in industrial processes. Energetic electron beams are now used to crosslink heat-shrinkable plastic film and tubing, crosslink the insulation on electrical wire and cable, cure polymeric coatings on wood and metal substrates and improve the "green" strength of rubber tire components. A relatively new application is the sterilization of medical devices with high-energy electrons. Further possibilities are the disinfection of sewage sludge, the extraction of pollutants from exhaust gases and the preservation of food (1).

Electron beam processing was introduced during the 1950's, was gradually accepted during the 1960's and has been widely applied during the 1970's. The impetus for this expansion has come not only from the superior quality of irradiated products but also from the higher production rates and lower costs of electron treatment processes. The rising cost of thermal energy and the increasing concern about environmental pollution from conventional manufacturing methods are also focussing attention on these new techniques (2).

The breadth of interest in this field has been demonstrated by the attendance at the First and Second International Meetings on Radiation Processing (3,4). Most of the participants at these meetings represented industrial organizations. At this time there are over 100 firms using more than 200 electron accelerators with a combined beam power approaching 10,000 kilowatts. The total value of products irradiated during 1979 probably exceeded two billion dollars. The growth rate of the radiation processing industry is now about 15 to 20 percent per year (5).

This mature technology can readily be applied to the in-plant treatment of meat and other food products. Relatively thin packages, such as sliced bacon and cold cuts, can be processed at high thruput rates with a powerful electron beam. Thicker objects, such as poultry and ham can be processed at lower thruput rates with more penetrating x-rays generated by an electron beam. The production capacities and estimated costs for these irradiation methods are discussed in this paper.

EQUIPMENT

The basic concept of a direct-action electron accelerator is shown by the diagram in Fig. 1. It consists of a high voltage generator connected to an electron gun, an evacuated acceleration tube and a beam scanner. The operation of this system is similar to a television picture tube, except that the voltage and power levels are much higher. For electron beam processing, the target plate consists of a thin metal foil that permits the beam to emerge into the air and irradiate nearby objects.

Direct-action electron accelerators are now available with voltage ratings from 0.5 to 5.0 million volts and beam power ratings from 20 to 200 kilowatts (6). Indirect (microwave) acceleration techniques can also be used to produce higher electron energies, up to the equivalent of 10 or more million volts, in the beam power range of 25 to 75 kilowatts.

The layout of a typical industrial facility is shown in Fig. 2. This consists of the electron accelerator, a thick-walled radiation shield usually made of concrete, and a conveyor to transport products through the electron beam. Operating personnel are quite safe outside this type of facility and can enter the treatment room to service the equipment when the high-voltage generator is not energized. There is no residual radiation or radioactivity in the equipment or the irradiated products after the electron accelerator has been switched off.

ELECTRON TREATMENT

The voltage rating of the electron accelerator determines the maximum thickness of the irradiated product. For example, a 5 million volt unit can penetrate up to 1.8 centimeters of meat (with equal entrance and exit doses) while a 10 MeV unit can treat up to 3.8 centimeters (1.5 inches). Two-sided irradiation would permit slightly more than twice these thicknesses (7).

The beam power rating determines the maximum production rate. Theoretically, a 1 kilowatt beam can process up to 360 kilograms per hour with an average radiation dose of 1 megarad. Practical thruput rates might be only 25 to 50 percent of this value depending on the product shape and configuration on the conveyor (7). In any case, a 100 kW unit would have a very high production capacity, up to 100 million kilograms per year (in 6000 hours at 25% power utilization efficiency and 0.5 Mrad minimum dose). A dose of 0.5 Mrad would not guarantee sterility but would be sufficient to extend the shelf life of refrigerated meats (8).

X-RAY TREATMENT

Penetrating x-rays (bremsstrahlung) are produced when high-energy electrons strike dense materials such as tungsten or gold. This form of radiation produces the same chemical and biological effects as energetic electrons and can be used to treat bulky objects and packages up to 30 centimeters in thickness. The conversion of electron beam power to x-ray power is an inefficient process but it can be competitive with Cobalt-60 gamma radiation for high capacity plants. The possibility of using either x-rays or electrons in the same facility is an attractive feature of this technology.

A proposed 6 MV, 300 kW electron accelerator, used as an x-ray generator, would have the processing capability of a 3 megacurie Cobalt-60 facility (9). The thruput rate is estimated to be about 60 million kilograms per year (in 6000 hours at about 5% power utilization efficiency and 0.5 Mrad minimum dose). This is comparable to the annual production rates of chicken or ham in large meat processing plants.

ECONOMICS

The price of a high-power electron accelerator in the 3 to 6 million volt range will fall between 1 and 2 million dollars (10). The total capital cost of a complete irradiation facility, including the accelerator, will be somewhere between 2 and 4 million dollars, depending on the size of the machine and the complexity of the product handling system. Annual operating costs, including amortization of capital, interest, electrical power, equipment maintenance and supervisory labor will be in the range of 0.5 to 0.9 million dollars (based on 6000 operational hours per year) and hourly operating costs will be between 80 and 150 dollars.

For direct electron treatment, assuming a conservative yearly thruput of 100 million kilograms and a median cost estimate of 0.7 million dollars per year, the unit processing cost would be about 0.7 cents per kilogram (at a minimum dose of 0.5 megarad). For x-ray treatment, assuming a yearly thruput of 60 million kilograms and the maximum cost estimate of 0.9 million dollars per year, the unit processing cost would be about 1.5 cents per kilogram (also at 0.5 megarad).

The unit cost would be somewhat higher for smaller plants since the capital costs do not scale down in proportion to the electron beam power ratings. Nevertheless, these cost estimates are probably low enough to be unimportant in an assessment of the radiation treatment process.

CONCLUSIONS

The high-power electron accelerators that are now being used to irradiate industrial products can also be applied for the treatment of meat and other foods in large-scale processing plants. Both primary electron beams and secondary x-rays can be used to accomodate a wide variety of package sizes and shapes. Production rates will be high enough and operating costs will be low enough to satisfy business requirements.

The substantial industrial experience with this type of equipment has amply demonstrated the reliability and safety of on-line radiation processing with electron accelerators. The technology is ready now to support any future demand for irradiated foods.

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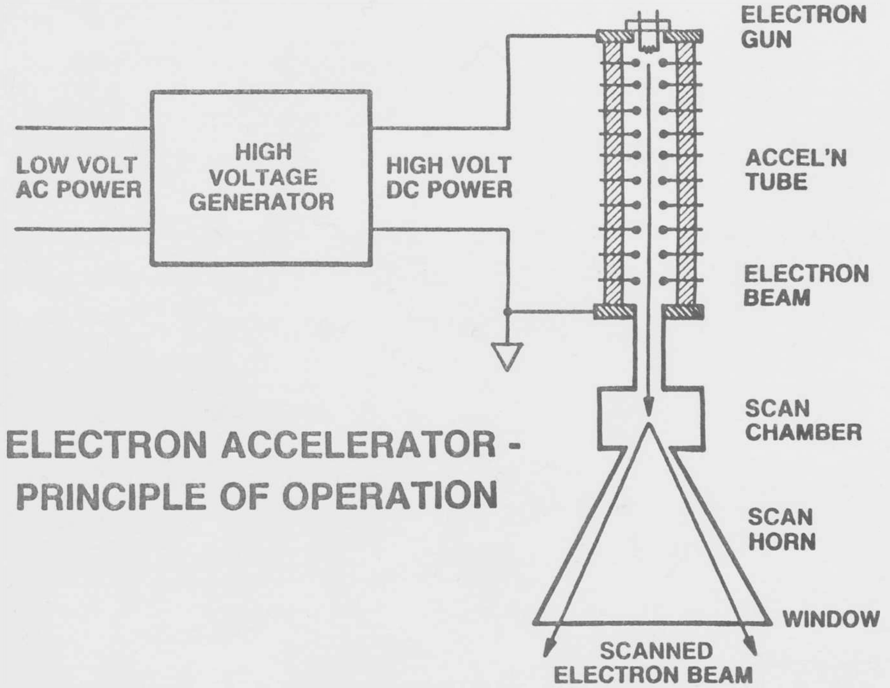

FIGURE 1

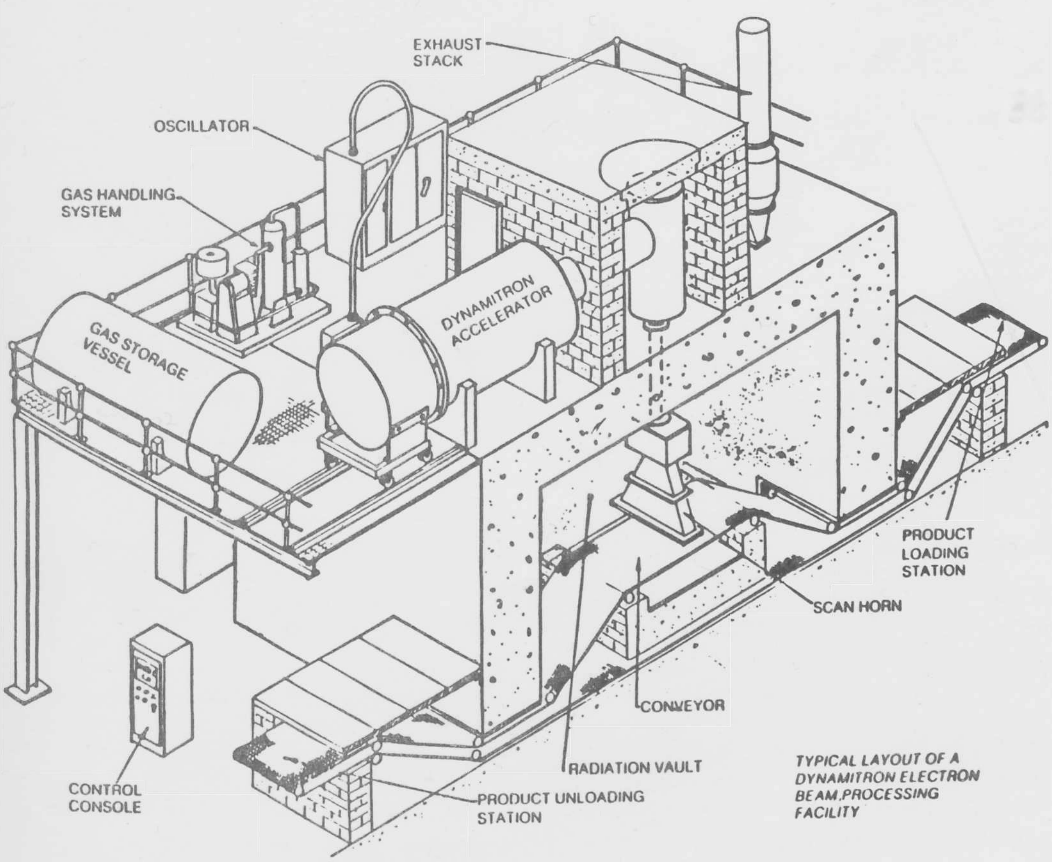

FIGURE 2