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ENERGY AND FOOD IRRADIATION

Ari Brynjolfsson

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RADIATION PRESERVATION OF FOOD DIVISION

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This paper shows that significant energy savings can be obtained by use of irradiation preservation. The energy used in food systems in the US amounts to about 16.5% of the total energy. An analysis of the energy used in the many steps of the food irradiation process found that irradiation pasteurization uses only 21 kJ/kg, radappertization 157 kJ/kg, which is much less than the energy used in the other food processes. A comparison has also been made with other methods of preserving, distributing, and preparing the meat for

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servings. It is found that food irradiation can save significant amounts of energy. In the case of heat sterilized and radiation sterilized meats, the largest fraction of energy used is in the packaging, while in the frozen meats, the largest energy consumption is by refrigeration in the distribution channels and in the homes.

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PREFACE

The ability to preserve food and store it from time of abundance to time of shortage, and the ability to transport the food from areas of surplus to areas of scarcity is a prerequisite for civilization. Many of our food preservation methods are energy demanding and becoming increasingly expensive to maintain in the developed countries; will be even more costly to introduce in the developing countries. This paper shows that significant energy savings can be obtained by use of irradiation preservation.

This report was presented by Dr. Ari Brynjolfsson at the International Symposium on Food Preservation by Irradiation, 21-25 November 1977, Wageningen, Netherlands.

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INTRODUCTION

As population grows, new land must be plowed, crop yields per acre must increase, and food losses need to be reduced. To do this we must use more tractors to pull the plows, more fertilizers to multiply our crop yields, and more of energy demanding technology to preserve our perishable foods. A man and a tractor today can do the work of 50 men and 50 horses 100 years ago. In the last twenty years the use of fertilizers worldwide has about quadrupled from 21.9 million tons in 1956 to about 85 million tons today, thereby increasing our food supply enough to feed about 1 billion people. The preservation and processing technology of food helps us keep the food nutritious and to store it from time of abundance to time of shortage, and to move it from areas of surplus to areas of scarcity. A key to this increase in the food supply has always been the nonrenewable energy resources, which are now dwindling. As these dwindle, we are forced to consider other ways to increase our food supply that demand less energy than those used in the past. If preservation of food by irradiation saves 30,000 kJ per kg, when compared with frozen food, we might prefer to invest that energy in about 0.38 kg of nitrogen fertilizer to increase our crop yield by about 3.8 kg. In this paper, we seek to illustrate with a few examples the energy needs for different poultry processing methods.

Compared to the energy used for retorting, refrigeration, or frozen storage, the energy used for irradiation preservation of food is small. Radpasteurization (pasteurization by radiation) of food corresponds to absorbing about 2.5 kJ/kg which will raise the product temperature less than 1°C. Radappertization (sterilization by radiation) corresponds to absorbing about 30 kJ/kg. A typical irradiation efficiency is 35% (i.e. 35% of the radiation energy emitted by the source is absorbed in the food). The source may be used 68% of the time resulting in an overall efficiency of 24%. The radiation energy used in radpasteurization is then 10 kJ/kg. The energy for conveyors, airblowers, and the like, will be about 11 kJ/kg, for a total energy consumption of 21 kJ/kg for 2.5 kGy radpasteurization. The corresponding total energy consumption in radappertization will be about 160 kJ/kg. Energy consumption in other processes will be shown in Table 3 for comparison.

The energy used in food processing is only a small fraction of the energy used in the entire food system, which includes production, processing, storage, distribution, and home preparation. In the United States, it has been estimated that 16.5% of the total energy consumption, which in 1970 was $7.27 \cdot 10^{19}$ J, was used in the food system.[1] This corresponds to approximately $1.62 \cdot 10^5$ kJ per person each day. Each person needs about 3000 kcal or $1.25 \cdot 10^4$ kJ/day in nutritional energy. The average energy used in the food system is thus 12.8 times the nutritional energy of the food consumed.

Any step in food processing can affect other steps in the food energy system. For instance, the heat sterilization step (retorting) will affect packaging, nutrition, storage, transport, distribution, and home storage and preparation.

In our analysis of energy use, it is important, therefore, to consider the impact of food irradiation on the energy used in the entire food system, including and subsequent to processing. As the first step, we will analyze the energy used in the food irradiation process.

ENERGY USE IN THE FOOD IRRADIATION PROCESS

The total energy used in the food irradiation process includes the radiation energy from the sources; the energy used in conveying the product through the irradiation cell; the energy used by auxiliary equipment such as water pumps, airblowers, etc.; the energy used by the control equipment; and the energy used for illuminating, heating, and cooling the irradiation facilities. Amortization of the energy invested in constructing the source, source frame, source elevator, source pool, conveyors, concrete shielding, loading area, control room, and dosimetry laboratory must also be included.

To illustrate such an energy evaluation we will consider an irradiation facility having 60 kW of Co-60 gamma ray radiation, i.e. $1.5 \cdot 10^{17}$ Bq ($4.054 \cdot 10^6$ Ci) of Co-60. Such a facility could pasteurize 30 metric tons of meat per hour or 180,000 metric tons per year (6000 hr/year) if the minimum pasteurization dose is 2.5 kGy (250 krad) and the radiation efficiency is 35%. (See Eq. (3) of ref. 2). By slowing down the conveyor, the same facility could

[1]Joint Committee on Atomic Energy Report, Understanding the National Dilemma, Center for Strategic and International Studies (1973).

[2]A. Brynjolfsson, Factors Influencing the economic evaluation of irradiation processing. Factors influencing the Economical Application of Food Irradiation, IAEA, Vienna, (1973).

instead be used to radappertize, with a dose of 30 kGy, 2.5 metric tons an hour or 15,000 metric tons a year. In a 6000 hr/year operation with 20% of initial investment applied each year to taxes, insurances, interest, and the like, the cost of irradiation would be 0.39¢/kg or 0.18¢/lb. (See Table 10 of ref. 2). We may think of this as boxed chicken or boxed retail cuts of red meat, irradiated at the end of a production line in a large meat packers processing plant. If some of the product must be sterilized at a dose of 3 Mrad, the irradiation cost for that product would be 4¢/kg or 1.8¢/lb. If the plants are 10 times smaller, the cost for irradiating would be about twice as high based on the analysis made in ref. 2. Refrigeration costs, if any, would be in addition to the irradiation costs.

Energy used during operation of an irradiation facility

An analysis of the energy used in one year in such a facility is shown in Table 1.

TABLE 1. ENERGY IN J/YR USED FOR OPERATING A 60-kW Co-60 FACILITY 6000 HOUR PER YEAR

Radiation energy from 60 kW ($4 \cdot 10^6$ Ci Co-60)[a]	$1.9 \cdot 10^{12}$
Conveyor 3,500 W (X 3.4)[b]	$2.6 \cdot 10^{11}$
Circulation pumps for pool 2,500 W (X 3.4)[b]	$2.7 \cdot 10^{11}$
Source elevator	$1.5 \cdot 10^{8}$
Airblower 2,000 W (X 3.4)[b]	$1.5 \cdot 10^{11}$
Control 1,000 W (X 3.4)[b]	$7.3 \cdot 10^{10}$
Lights 1,000 W (X 3.4)[b]	$7.3 \cdot 10^{10}$
Total energy joule/year used during operation	$2.7 \cdot 10^{12}$

[a]The energy used in the production of Co-60 is shown in Table 2. If we have $3.7 \cdot 10^{12}$ Bq/g (100 Ci/g) of cobalt then the total radiation energy emitted over the lifetime of cobalt is $3.5 \cdot 10^{11}$ J/kg, which far exceeds the energy used in its production. The radiation energy from the Co-60 is usually derived

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from excessive neutrons in a reactor (flux-flattening) and could be considered waste. We will, nevertheless, consider the Co-60 as an available energy source.

[b]All energy used in the form of electricity is multiplied by 3.4 to account for conversion losses from heat to electricity generation and to account for losses in delivering the electricity from place of generation to place of use.

Energy used in construction of an irradiation facility

In addition to the energy used in operation of the facility, we must consider the amortization of energy in capital layouts such as buildings and machinery. See Table 2.

TABLE 2. ENERGY IN J USED FOR CONSTRUCTION OF A 60-kW Co-60 FACILITY

Source modules & frames (2,000 kg)	$1.7 \cdot 10^{11}$
Conveyor (10,000 kg)	$8.7 \cdot 10^{11}$
Source storage pool (8,000 kg)	$6.9 \cdot 10^{11}$
Concrete shielding	$6.5 \cdot 10^{12}$
Control room, dosimetry room, and loading area	$2.0 \cdot 10^{12}$
Instruments for control room and dosimetry	$1.0 \cdot 10^{11}$
Water and heat exchanger pumps & airblowers	$2.7 \cdot 10^{11}$
Source production	$1.0 \cdot 10^{11}$
Transportation of sources to site	$3.0 \cdot 10^{11}$
	$1.1 \cdot 10^{13}$

We will amortize over 5 years the energy used in source production and the source transportation and the remainder of this energy used over 10 years or by $1.1 \cdot 10^{12}$ J/yr.

Energy used for irradiating food

From Tables 1 and 2 we find then an operational energy of $2.7 \cdot 10^{12}$ + $1.1 \times 10^{12} = 3.8 \cdot 10^{12}$ J/yr or about twice the radiation energy of $1.9 \cdot 10^{12}$ J/yr.

The energy used per year in irradiating $1.8 \cdot 10^{8}$ kg of product with a dose of 2.5 kGy is then $3.8 \cdot 10^{12}$ J/($1.8 \cdot 10^{8}$ kg) = 21 kJ/kg. Had the dose required been a sterilizing dose of 30 kGy, a similar analysis would show that the energy used in the process would be about 157 kJ/kg. This increase would result primarily from an increase in source strength.

For the purpose of an overview, we list in Table 3 the energy used in different food preservation processes.

TABLE 3. TYPICAL ENERGY VALUES IN kJ/KG USED FOR PROCESSING OF FOOD

Radpasteurization with 2.5 kGy	21
Radappertization with 30 kGy	157
Heatappertization (heat sterilization) (Step 66 of [3])	318
Blast-freezing chicken from 4.4°C to -23.3°C (Step 16 of [3])	7552
Storing the product at -25°C (Step 19 of [3]) for 3.5 weeks (588 hr.)	5149
Refrigerated storage for 5.5 days at 0°C (Step 30 of [3])	318
Refrigerated storage for 10.5 days at 0°C (Step 32 of [3])	396
Cooking whole thawed chicken at 93°C (Step 33 of [3])	2558

[3] S. Dwyer, III, K. Unklesbay, N. Unklesbay, C. Dunlap, Identification of Major Areas of Energy Utilization in the Food Processing/Food Service Industry. (National Science Foundation Grant Number SIA 75-16222). University of Missouri, Columbia (1977).

This analysis shows that the energy 21 kJ/kg used for radpasteurizing the product with 2.5 kGy is rather insignificant when compared with the energy cost of refrigerated storage of food. Also, the energy cost of 157 kJ/kg for radappertizing the food with 30 kGy is small when compared with heatappertization and with freezing and frozen storage.

PACKAGING

Packaging is a major factor in preserving food. The principal purposes of packaging are to prevent recontamination by bacteria, to prevent oxygen deterioration, and to prevent insect and rodent damage. Packaging is also used to prevent water re-absorption and oxidation in foods stabilized by drying. Packaging is essential for retaining food quality. Although packaging is often very expensive, it may still be cost effective if product deterioration is prevented. The significance of food irradiation for packaging cost is that the selection of materials used becomes greater. We may, for instance, be able to select materials that cannot tolerate the abuse of thermal heat sterilization. We may be able to prepare food in a manner which will better preserve its nutrients, and we may be able to reduce energy used in packaging.

The reliability of the tinplate can and the flexible pouch materials has been described by Killoran et al.[4,5], who report significant improvements in the bond strength of the plastic-aluminum laminates. The United States Food and Drug Administration has already cleared a great many packaging materials.[6] For the different packaging materials we use the energy figures used by Hoddinott [7], that is, 50,000 kJ/kg can materials, and 40,000 kJ/kg of carton material.

TRANSPORTATION

As an example we will estimate the energy need for transporting frozen and unfrozen meats. We will ship 10^4 kg of food in a truck weighing 12 tons

[4] J.J. Killoran, J.J. Howker, and E. Wierbicki, Reliability of the tinplate can for packaging of irradiated beef under production conditions. Presented at First International Congress on Engineering and Food, 9-13 August 1976, Boston, MA, USA. To be published in proceedings.

[5] J.J. Killoran, J.S. Cohen, and E. Wierbicki, Reliability of flexible packaging of radappertized beef under production conditions. Paper presented at First International Congress on Engineering and Food, 9-13 August 1976, Boston, MA, USA. To be published in proceedings.

a distance of 300 highway km and 100 city km. The truck is loaded, driven the distance, and unloaded within 24 hours. To produce the truck will cost about $9 \cdot 10^7$ J/kg. We will assume that the life of the truck is 300,000 km. The depreciation cost per km will then be $9 \cdot 10^7 \cdot 12 \cdot 10^3/300{,}000 = 3.6 \cdot 10^6$ J/km. The energy cost per highway km will be about (See ref. 3 for fuel consumption data.)

$$E_1 = \text{energy in J/km} = 3.6 \cdot 10^6 + 1.0 \cdot 10^7 + (6.5 \cdot 10^2) \cdot (\text{Gross weight in kg})$$

The energy cost per city km will be about (See ref. 3 for fuel consumption data.)

$$E_2 = \text{energy in J/km} = 3.6 \cdot 10^6 + 1.1 \cdot 10^7 + (8.6 \cdot 10^2) \cdot (\text{Gross weight in kg})$$

For a gross weight of $2.2 \cdot 10^4$ kg we have:

$E_1 = 2.8 \cdot 10^7$ J/km on highway

$E_2 = 3.3 \cdot 10^7$ J/km in city.

If we drive 300 km on a highway and 100 km in the city with 10^4 kg of food, the energy used per kg of food will be $1.2 \cdot 10^6$ J/kg. The energy used in refrigeration at -20°C during the 20-hr transport period will be about $1.5 \cdot 10^8 \cdot 20 = 3 \cdot 10^9$ J when the difference between the ambient and product temperature is 40°C (see ref. 3). During 2 hr loading and 2 hr unloading, the energy used will be about $7.5 \cdot 10^8 \cdot 4 = 3 \cdot 10^9$ J. The energy used in refrigeration during transport will then be $6 \cdot 10^5$ J/kg of food. Refrigeration, therefore, increases the energy used in shipment from $1.2 \cdot 10^6$ J/kg to $1.8 \cdot 10^6$ J/kg or 50%. Had the shipment been at 0°C, the energy used in refrigeration would have been $3 \cdot 10^5$ J/kg of food.

[6] E.S. Josephson, A. Brynjolfsson, E. Wierbicki, D.B. Rowley, E. Merritt Jr., R.W. Baker, J.J. Killoran, M.H. Thomas, Radappertization of meat, meat products, and poultry. Paper presented at First International Congress on Engineering and Food, 9-13 August 1976, Boston, MA, USA. To be published in proceedings.

[7] R.I. Hoddinott, The retortable pouch: advantage to processor, retailer, consumer, Package Development 25, March/April (1975).

COMPARISON OF DIFFERENT PROCESSES OF CHICKEN

We will compare the energy use for different conventional methods of processing chicken with irradiation processing of chicken. The chicken are slaughtered, defeathered, eviscerated, and chilled to about +3°C, the giblet is separated, the chicken carcasses are cut up. Short-term refrigerated storage is usually necessary before further processing. About 990 kJ/kg is used in these operations (see Table 6.30 of ref. 3).

We must add to this the energy used in packaging materials. Plastic films and trays for cut up chicken weigh about 15 g per kg of cut-up chicken. The energy content of the plastic film and trays is about 50,000 kJ/kg[7]. The energy cost of the trays and film is then about 750 kJ per kg raw cut-up chicken.

To this we add the energy cost for carton boxes. We use about 60 g of box material per kg of food. The energy content of this box material is about 40,000 kJ/kg. The energy cost of the carton boxes is then about 2400 kJ/kg of raw cut-up chicken.

In thermal processing, we use about 140 g of can material per kg of food. The energy content of can material is about 75,000 kJ/kg. The energy cost of the can material is then about 10,500 kJ per kg of canned food.

The energy cost of plastic-aluminum laminate film for packaging is described by Killoran in ref. 5 for packaging of radappertized food. This film is 62 μm polyethylene, 2.5 μm adhesive, 9 μm aluminum foil, 2.5 μm adhesive, and 25 μm nylon 6. The energy content of the plastic layers is about 50,000 kJ/kg, and of the aluminum is about 300,000 kJ/kg. This results in 1100 kJ per cm^2 of film. If this plastic-aluminum laminate film is used to package very long meat rolls 10 cm in diameter (see ref. 5 for details of meat roll preparation) the energy cost would be about 300 kJ per kg of meat. For 10-cm long cylinders the energy cost would be about 400 kJ per kg of meat. For individual servings (140-g) packages the energy cost of the package is about 1500 kJ/kg.

The energy used in blast-freezing is about 7560 kJ/kg (see step 16 of ref. 3) and for frozen (-25°C) storage in large warehouses is about 9 kJ/kg hr. (see step 19 of ref. 3).

Shipping by truck 200 km (see previous section) would cost about 600 kJ/kg; and the added cost for refrigeration during shipment, loading and unloading would be 150 kJ per kg of food.

The energy used in the retail market is about 300 kJ/kg of refrigerated food, and 600 kJ/kg for frozen (-20°C) food. No good estimates for the energy used were available. This rough estimate was calculated from data obtained by observing the design and practice in one supermarket.

The energy used for frozen home storage is about 8000 kJ/kg of food and the energy used for refrigerated home storage is about 3,000 kJ/kg.[8]

Home preparation costs about 3,000 kJ/kg for raw frozen and refrigerated food[8] and up to 2,000 kJ/kg for cooked food. Cut-up chicken contains about 37% bones; the edible portion is then 63%. We will now use these estimates to compare the energy used in different processes and the subsequent handling and treatment of the food.

Example 1

Energy Used (kJ/kg) of Refrigerated Chicken

Usually the chickens are cut up and marketed refrigerated at 0 - 5°C. Sometimes chilling to -2 - 0°C is applied. This last mentioned process will increase the energy used but it extends the time for marketing.

TABLE 4. ENERGY USED IN kJ/KG OF REFRIGERATED 0 - 5°C CHICKEN

From slaughter to cut-up chicken	990
15 g plastic film and trays per kg chicken	750
60 g carton boxes per kg chicken	2,400
Shipment by truck	600
Refrigeration during shipment	150
Retail marketing	300
Home refrigeration	3,000
Home preparation	3,000
Total kJ per kg of cut-up chicken	11,190
Total kJ per kg of edible portion (63%)	17,760

[8] Y.S. Henig, H.M. Schoen, Energy and Food - An Overview. Presented at the First International Congress on Engineering and Food, Boston, MA. August 1976. To be published in proceedings.

Example 2

Energy Used (kJ/kg) for Radpasteurized Chicken

Irradiation with 2.5 kGy can be used to reduce or eliminate salmonella. This dose will also extend the shelf-life from about 7 days to about 2 to 3 weeks.

The energy used for irradiation is 21 kJ/kg. The refrigeration energy used to maintain uniform temperature during the 1/2 hr. transit through the irradiation facility is about 40 kJ/kg. Other energy uses are the same as in Example 1 above.

TABLE 5. ENERGY COST IN kJ/KG FOR REFRIGERATED AND RADPASTEURIZED CHICKEN

From slaughtering to cut-up chicken	990
15 g plastic film and trays per kg chicken	750
60 g carton boxes per kg chicken	2,400
Irradiation	20
Refrigeration during irradiation	40
Shipment by truck	600
Refrigeration during shipment	150
Retail marketing	300
Home refrigeration	3,000
Home preparation	3,000
Total kJ/kg of raw cut up chicken	11,250
Total kJ/kg of edible portion (63%)	17,860

Example 3

Energy Used (kJ/kg) for Frozen Chicken

Chicken processing will be the same as in Example 1 except that before shipment the chicken must be blast-frozen. The energy used is 7560 kJ/kg. Shipment in the frozen (-20°C) state will use an extra 150 kJ/kg (raising the total to 300 kJ/kg), and the storage in the retail store an extra about 300 kJ/kg.

TABLE 6. ENERGY USED IN kJ/KG OF FROZEN CUT-UP CHICKEN

From slaughter to cut-up chicken	990
15 g plastic film and trays per kg of chicken	750
60 g carton boxes per kg of chicken	2,400
Blast-freezing	7,560
Frozen storage 3-1/2 weeks*	5,150
Shipping by truck (200 km)	600
Freezing during shipment	300
Retail marketing	600
Home refrigeration	8,000
Home preparation	3,000
Total kJ per kg of raw cut-up chicken	29,350
Total kJ per kg of the edible portion (63%)	46,600

*This is a conservative estimate.

Example 4

Energy Used (kJ/kg) for Cooked and Frozen Chicken Rolls

Presently, fully cooked chicken rolls being marketed and stored frozen. Because no energy is used in freezing, storing, and shipping the bones, this product is less energy-demanding than the frozen raw cut-up chicken.

TABLE 7. ENERGY COST IN kJ/KG OF COOKED FROZEN CHICKEN ROLLS

From slaughter to deboning and mixing	1,080
Casings (30 μ thick)	60
Blanching (heating to 70°C)	800
Packaging into carton boxes	2,400
Blast-freezing	7,560
Storage	5,150
Shipping by truck (200 km)	600
Freezing during shipment	300
Retail marketing	600
Home refrigeration	8,000
Home preparation (0 to 2,000 kJ/kg, on an average)	1,000
Total kJ/kg edible portion	27,550

Example 5

Energy Used (kJ/kg) for Thermally Processed Chicken

Thermal processing results in a significant loss of product quality, and in the production of distinctly different products, such as retorted canned chicken meat, chicken broth, and chicken fat. Reference 3, steps 61 to 68, analyzes the energy consumed in thermal processing. Table 6.30 of Reference 3 shows energy consumption in thermal processing to be 5,680 kJ/kg (2,442 Btu/lb).

TABLE 8. ENERGY USED IN kJ/KG FOR RETORTED CHICKEN

Canned diced chicken	5,680
Can material	10,500
Carton boxes	2,400
Storage	0
Shipping by truck	600
Retail marketing	0
Home refrigeration	0
Home preparation (0 to 2,000 kJ/kg, on an average)	1,000
Total kJ per kg edible portion	20,180

Example 6

Energy Cost (kJ/kg) of Radappertized Chicken

The chickens are slaughtered, defeathered, eviscerated, chilled to 0°C, deboned, excessive fat removed, cut up, mixed, and put into casings that are approximately 10 cm in diameter and 100 cm long. These meat rolls in casings are placed in a cookhouse (smokehouse) for heating to blanching temperatures about 70°C. When cooled down, the meat rolls may be vacuum packaged in plastic/aluminum laminated foil cylinders and then packed in carton boxes. The boxes are blast-frozen and sent through the irradiation facility for radappertization at -40°C. The present technology results in highly acceptable meat products when the irradiation is performed at low temperatures.

TABLE 9. ENERGY USED IN kJ/KG OF RADAPPERTIZED CHICKEN FOR INSTITUTIONAL FEEDING

From slaughter to deboning and mixing	1,080
Casings 30 μ thick	60
Blanching (heating to 70°C)	800
Packaging the 100 cm rolls into plastic/aluminum laminate	300
Packing into carton boxes	2,400
Blast-freezing	7,560
Irradiation	160
Cooling during irradiation	300
Storage	0
Shipping by truck	600
Retail distribution	0
Home storage	0
Home preparation 0 to 2,000 on an average	1,000
Total energy in kJ/kg edible portion	14,260

We have in Table 7 used for blast-freezing the value of 7,560 kJ/kg from ref. 3. In food irradiation the food can be thawed after irradiation and the thawing meat can be used to cool incoming unirradiated meats.

Example 7

Energy Used in kJ/kg of Radappertized Chicken in Individual Serving Packages

Radappertized meats when prepared as individual servings of about 140 g have a great advantage over other preservation methods because they are ready to eat. The meat slices can be served without much preparation of in sandwiches as used by the astronauts on the Apollo-Soyuz flight. These advantages are not reflected in the energy evaluation.

TABLE 10. ENERGY USED IN kJ/KG FOR RADAPPERTIZED COOKED INDIVIDUAL SERVINGS ENERGY CONSUMPTION

From slaughter to deboning and mixing	1,080
Casings 30 μ thick	60
Blanching (heating to 70°C)	800
Cutting and packaging into pouches	1,500
Packing into carton boxes	2,400

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TABLE 10. (CONT'D)

Blast-Freezing	7,560
Irradiation	160
Cooling during irradiation	300
Storage	0
Shipping by truck	600
Retail distribution	0
Home storage	0
Home preparation (0 - 2,000 on average)	1,000
Total energy in kJ/kg edible portion	15,460

Summary of Energy Used in Processing Chicken

For an overview we list in Table 11 the energy used in kJ/kg, of the edible chicken portion.

TABLE 11. SUMMARY: ENERGY USE (kJ/KG) ASSOCIATED WITH DIFFERENT CHICKEN PROCESSING METHODS

Refrigerated raw cut-up chicken	17,760
Refrigerated and Radpasteurized raw cut-up chicken	17,860
Frozen raw cut-up chicken	46,600
Frozen cooked long chicken rolls	27,550
Retorted canned chicken meat	20,180
Radappertized cooked long chicken rolls	14,260
Radappertized cooked individual servings	15,460

Analysis of energy used in processing meat products other than chicken would be very similar. In case of radpasteurized meats we have added the radpasteurization process to the present practice of refrigeration. We have not taken into account the reduced loss because of spoilage, the reduced salmonella hazard, and the added flexibility in distribution.

The radappertization process is the least expensive in energy. This is mainly because of energy savings in storage. Radappertized enzyme-inactivated meats can be stored several years. We would have, therefore, a high degree of safety and reliability in distribution which, from the public health point of view, must be considered very important especially in countries where a refrigerated distribution and marketing system has not been highly developed or where there are only a few home refrigerators. The fact that the food can be stored inexpensively should, for industry, facilitate marketing and make it easier to adjust to fluctuations in production and demand for the product. A developing country may be particularly interested in the fact that the radappertization processing of meats can be developed independently of an advanced distribution system, that it does not depend on special refrigerated trucks, nor good transportation, nor does it require refrigerators in stores, or in homes.

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