CONTROL OF SALMONELLA IN MEAT AND MEAT PRODUCTS
BY IRRADIATION

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INTRODUCTION

Food-borne diseases are now (1985) serious health problems in nearly all parts of the world. Even the most advanced countries suffer from a tremendous incidence of food infections attributable to food of animal origin, (Mossel and van Netten, 1981). As far as meats and poultry are concerned, Salmonella is presently the most important causal agent of food infections in most countries: the occurrence of 'Salmonellosis' in man showing a significant increase during the last 30 years. Kampelmacher (1983) lists 6 factors responsible for this state of affairs, see Table 1. They are:

1. Changed animal husbandry practices.
2. Mass production and processing of foods.
3. Migration of people (tourists/guest workers).
5. Increased trade in food and feed.
6. Increased environmental pollution resulting in food and feed contamination.
Salmonella

The enteric bacilli comprising the large salmonella group consist of some 1,700 serological types (Diane Roberts, 1982) are all pathogenic to a greater or lesser extent and include the typhoid bacillus, the paratyphoid bacilli and a wide variety of forms whose natural hosts are lower animals especially rodents and birds.

TABLE 1: Factors responsible for increase in incidence of Salmonellosis

1. Changes in animal husbandry methods, e.g. mass breeding/fattening methods.
2. Mass production and processing of food.
3. Migration of millions of people (tourists/guest workers).
4. Changing food habits, e.g. increased eating-out and purchase of cold, cooked items such as barbecued chicken.
5. Increased trade in foods and feed.
6. Increased environmental pollution.

Source: Kampelmaucher (1983)
Food Tech. 37, 117

These bacteria are Gram negative rods closely resembling and indistinguishable from coliform bacteria. They are non-sporing and average between 2 and 4.0 x 0.5 μ in size. All species are motile except the poultry strains, Salm. pullorum and
Salm. gallinarum. Their optimum growth temperature is 37\degree but
growth takes place over the range 5\degree - 47\degree C (Bryan 1979). Growth 
below 10\degree is very slow. The thermal death point is 56\degree C. They are 
facultative anaerobes growing equally well under aerobic or anaerobic 
conditions.

Gastroenteritis or food poisoning by salmonellae results 
from the ingestion of large numbers of organisms which multiply 
in the small intestine. The illness is characterised by a short 
incubation period, as little as 12h in some cases, with acute 
vomiting and diarrhoea and only a slight rise in body temperature 
and rapid recovery within a few days. Occasionally salmonellosis 
develops into a more serious septicemic condition. It is an 
infection rather than an intoxication.

Irradiation

The possibility of using ionising radiation (IR) for the 
treatment of food for preservation or other purposes, e.g. (control 
of salmonella in meat/meat products) has attracted the attention 
of workers in many countries during the last 30 years (Ley 1983). 
But the application of I.R. in the Food Industry has been small and 
often confined to pilot-scale processing and market trials, 
largely due to the question of safety. However, the extent of interest 
is gauged by reference to Table 2. It is seen that a wide variety 
of meats, both raw and processed, have been subjected to I.R. 
for various purposes; extension in shelf-life being the most usual.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Type of Product</th>
<th>Purpose</th>
</tr>
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<tbody>
<tr>
<td>Wolin et al (1957)</td>
<td>Packaged beef sirloin</td>
<td>Shelf life extension</td>
</tr>
<tr>
<td>Coleby et al (1962)</td>
<td>Pork sausage in cellophane/polythene bags</td>
<td>Pasteurisation</td>
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<tr>
<td>Rhodes &amp; Meegungwan (1962)</td>
<td>Lamb's liver</td>
<td>Inactivation of enzymes</td>
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<tr>
<td>Anellis et al (1965)</td>
<td>Canned bacon</td>
<td>Sterilization</td>
</tr>
<tr>
<td>Rhodes &amp; Shepherd (1966)</td>
<td>Vacuum packaged beef and lamb</td>
<td>Pasteurisation</td>
</tr>
<tr>
<td>Rhodes et al (1967)</td>
<td>Barley-fed beef</td>
<td></td>
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<tr>
<td>Rhodes &amp; Shepherd (1967)</td>
<td>Green bacon</td>
<td>To delay spoilage</td>
</tr>
<tr>
<td>Tiwari &amp; Maxcy (1971)</td>
<td>Ground beef</td>
<td>Influence of irradiation on microflora</td>
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<tr>
<td>Mossel et al (1972)</td>
<td>Frozen boneless meat</td>
<td>Organoleptic evaluations</td>
</tr>
<tr>
<td>Maxcy &amp; Tiwari (1973)</td>
<td>Minced meat</td>
<td>Shelf life extension and public health protection</td>
</tr>
<tr>
<td>Welch &amp; Maxcy (1975)</td>
<td>Ground beef</td>
<td>Characterisation of radiation resistant bacteria</td>
</tr>
<tr>
<td>Anellis et al (1979)</td>
<td>Canned meat rolls</td>
<td>Destruction of food-borne pathogens</td>
</tr>
<tr>
<td>Wierbicki &amp; Heligman (1980)</td>
<td>Bacon</td>
<td>Effect of irradiation in presence and absence of nitrite</td>
</tr>
<tr>
<td>Dempster &amp; Lahola (1983)</td>
<td>Ground beef</td>
<td>Elimination of specific microbial species</td>
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</table>
Terminology

Irradiation processes may be divided very broadly into high
dose (>1 Mrad) and low dose (<1 Mrad) applications. The following
terminology has been introduced to take account of the different
levels in use in practice (Goresline et al 1964).

**Radappertisation** or radiation sterilisation is defined as the
treatment of food with I.R. sufficient to reduce the number of
microorganisms to such a level that very few, if any, are detectable
by any recognised bacteriological testing method. Doses used are
greater than 1 Mrad*. It is analogous to thermal sterilisation
as understood in the canning industry.

**Radicidation** is the application to foods of doses of I.R.
sufficient to reduce the number of viable specific non-spore forming
pathogenic microorganisms (other than viruses) so that none is
detectable in the treated food by any standard method. Doses for
this purpose are usually less than 1 Mrad and the process is
analogous to pasteurisation, for example, of milk.

**Radurisation** is defined as the exposure of food to doses which
substantially reduce the population of viable specific microorganisms
in order to enhance the keeping quality of food. Dose levels are
generally less than 1 Mrad.

Applications

(a) **Poultry**

One of the very promising possibilities for protecting the

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* 1 rad = 100 ergs of energy absorbed in 1 g. of matter.
1 Krad = 1,000 rad.
1 Mrad = 1,000,000 rad.
A new term recently introduced is the Gray (Gy) where
1 Gy = 100 rad.
consumer against 'the salmonella hazard' is the use of irradiation to eliminate these microorganisms from slaughtered poultry carcasses. In red meat, processes like infrared and ultraviolet radiation give good results in the decontamination of the meat surface. As the microbial contamination of a poultry carcass is not limited to the skin but also occurs in the abdominal cavity these processes are less applicable because of their low penetrating power. For the radiation treatment of poultry carcasses gamma-radiation can be used because of its high-penetration capacity. Low doses of ionising radiation have already been suggested many years ago to extend shelf life of broiler carcasses at refrigeration temperatures.

At the XVth session of the Codex commission on food additives (Codex 1982) a revised draft code for chicken was introduced. It stated that irradiation was to prolong storage life and/or reduce the number of certain pathogenic microorganisms like salmonella. The average recommended dose was not to exceed 7 k Gy (0.7 Mrad).

Salmonellae are isolated very frequently from broiler carcasses although the reported incidence is strongly influenced by the methods of sampling and examination used. For example, Goetz and Schroeder (1974) found that 32% of the carcasses they studied were salmonella-positive when a destructive technique was used. Dougherty (1974) in America, using a rinsing method found 47% positives while van Schothorst et al (1976) found, depending upon the sampling system used, that 25 - 64% of broiler carcasses were contaminated. However, irrespective of the method of examination; whether 100 g or 200 g skin or thaw water from deep-frozen (-20°C) broiler carcasses, no salmonellae were recovered after 250 Krad
treatment (Mulder et al 1977). Even lower dose levels have been used with success. Thus Mossel et al (1968) found that a dose of ca. 100 krad effected a ten-fold reduction in numbers of Enterobacteriaceae on broiler carcasses. These doses have been declared safe by the World Health Organisation which issued a press release in 1980 stating .... no health hazard results from consuming any food which is irradiated up to a dose of one megarad.

There is evidence that radiation treatment at freezer temperatures is less effective than the same dose at chill or room temperatures, (Thornley 1957: Maxcy 1982). Matsuyama et al 1964 studied the radiation resistance of a number of microorganisms in heart-infusion broth in aerated or anoxic conditions at temperatures of 10° - 13° or -79°. Survivor dose curves were plotted and Fig 1 shows the results for an Esch. coli sp. The decreased radiosensitivity in the frozen state was measured by comparing the D10 value with that for irradiation at room temperature. Similar results have been reported for other microorganisms, e.g. Pseudomonas aeruginosa (Moos 1952) and Staphylococcus aureus (Bellamy and Lawton 1955). The combined effects of low temperature (+ 5° and -18°) and irradiation (250 Krad) were studied by Mulder (1982) on salmonellae and other Enterobacteriaceae in broilers after 4 months storage. Results showed that irradiation at 5° resulted in Salmonella-negative samples after 1 month storage at -18° but irradiation after freezing gave a salmonella-negative result only after a 3 month storage period. Brynjolfsson (1980) presented data for the doses necessary to reduce the number of different serotypes of salmonella by a factor of 10^6 in different meat
Fig (1). Effect of irradiation on survival of E. coli B/r in heart-infusion broth. Suspensions were irradiated in air at 10^\circ - 13^\circ (circles); in air at -79^\circ (triangles) and in nitrogen at -79^\circ (squares).
Data from MATSUYAMA et al (1964)
substrates, see Table 3. It is evident that temperature of substrate plays a significant role in sensitivity of salmonellae to irradiation. He (Brynjolfsson 1980) pointed out resistance of microorganisms depends on the medium and the temperature. Vegetative organisms are often two or three times more resistant in the dry or frozen state than in water and they are less sensitive when irradiated anaerobically, i.e. in vacuum or in an inert atmosphere like nitrogen (see Fig 1) than when irradiated in the presence of oxygen. It is suggested that ice formation in frozen products protects bacteria against irradiation effects by markedly reducing the formation of free radicals (Anellis et al 1973). The presence of protein and polysaccharide may also provide protection.

TABLE 3: Dose of irradiation in kGy necessary to reduce the number of salmonellae in different meat substrates by a factor of $10^0$

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Substrate and Temperature</th>
<th>Dose</th>
</tr>
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<tbody>
<tr>
<td>Salm. heidelberg</td>
<td>Chicken 0°C</td>
<td>3.6</td>
</tr>
<tr>
<td>Salm. typhimurium</td>
<td>Beef 5°C</td>
<td>3.5</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot; -18°C</td>
<td>6.0</td>
</tr>
<tr>
<td>Salm. paratyphi</td>
<td>Beef liver 5°C</td>
<td>1.8</td>
</tr>
<tr>
<td>&quot;</td>
<td>Horse meat (frozen)</td>
<td>6.4</td>
</tr>
<tr>
<td>Salm typhosa</td>
<td>Corned beef 25°C</td>
<td>2.4 to 4.8</td>
</tr>
<tr>
<td>&quot; derby</td>
<td>Pork 10°C</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Source: Brynjolfsson (1980)
Beef

Irradiation is also effective in reducing numbers of potential pathogens in ground (minced) beef (Tiwari and Maxcy 1972; Dempster and Lahola 1983); frozen boneless beef (Mossel et al 1972) and sliced beef round (Wolin et al 1957). Niemand et al (1981) applied a dose of 2 kGy to vacuum packed beef stored at 4°C for 11 weeks with the results as shown in Table 4. It is seen that radurisation reduced the Enteric count by ca. 7 log cycles. Evaluations of the appearance and odour of the control and radurised samples were carried out at weekly intervals. Samples were allowed to develop a natural colour and odour in air when removed from the vacuum pack. The appearance and odour were evaluated on a simple three point scale, namely (a) A = excellent, (b) B = acceptable and (c) C = unacceptable. Smaller variations were indicated by a plus (+) or minus (-) sign. Results are shown in Fig 2. It is seen that the radurised samples had a significantly higher ranking (P<0.01) throughout the storage period for both appearance and odour evaluations. On the day of irradiation, experienced panellists could detect a faint but typical irradiation odour in radurised samples although it was not found to be objectionable. Judged by appearance and odour, control samples had a shelf life of 4 weeks whilst radurised meat (2 kGy) was still acceptable after 10 weeks storage at 4°C.

Processed meat

The rates of isolation of salmonellae from packets of pork sausage and sausage meat from large, medium and small manufacturers
TABLE 4: Effect of 2 kGy dose irradiation on numbers of Enterobacteriaceae in vacuum-packed beef cuts

<table>
<thead>
<tr>
<th></th>
<th>Count (log count g$^{-1}$) after storage at 4°C (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Control</td>
<td>2.51</td>
</tr>
<tr>
<td>2 kGy</td>
<td>&lt;1.0</td>
</tr>
</tbody>
</table>

Source: Niemand et al (1981) - modified

for the years 1968 - 1974 are presented in Table 5. The results indicate the possibility of higher rates of isolation from manufacturers taking in large numbers of animals from a wide area than from those dealing with small numbers of animals obtained locally. There was an average of 30% isolations from the various sources. Although the danger of cross-contamination from these products to other foods seems remote and they are not consumed in the raw state, nevertheless low-dose I.R. would eliminate whatever reservoir of Salmonella there may be. Such an approach warrants investigation.
Control samples

Radurised samples

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**Fig (2).** Evaluation of odour and appearance of control and radurised beef cuts. Odour and appearance evaluated on a 3-point scale, A = excellent; B = acceptable; C = unacceptable. Smaller variations were indicated by a plus (+) or minus (-) notation.

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**Statistical analyses**

A 2-way analysis of variance was performed on values obtained by transformation of the above as follows:

\[
A(+) = 3.5: A = 3: B(+) = 2.5: B = 2: C(+) = 1.5: C = 1: C(-) = 0.5
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>A</th>
<th>B</th>
<th>AxB</th>
<th>C.V. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odour</td>
<td>39.29***</td>
<td>26.89***</td>
<td>5.96***</td>
<td>17.62</td>
</tr>
<tr>
<td>Appearance</td>
<td>44.95***</td>
<td>34.91***</td>
<td>7.42***</td>
<td>18.19</td>
</tr>
</tbody>
</table>

**A** - storage time; **B** - treatments

*** P<0.01

**Source:** Niemand et al (1981)
TABLE 5: Salmonellae from packets of pork sausage and sausage meat for 1968 - 1974*

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of packets tested</th>
<th>Positive for Salmonella</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large manufacturer A</td>
<td>312</td>
<td>7</td>
</tr>
<tr>
<td>Large manufacturer B</td>
<td>854</td>
<td>413</td>
</tr>
<tr>
<td>Medium manufacturer C</td>
<td>101</td>
<td>4</td>
</tr>
<tr>
<td>Medium manufacturer D</td>
<td>100</td>
<td>16</td>
</tr>
<tr>
<td>Small manufacturers</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,467</td>
<td>435</td>
</tr>
</tbody>
</table>

NOTE: 38 different serotypes were isolated; the largest number of serotypes found in a single packet was four.


Recent Development

A significant development for the potential of ionising radiation occurred last year in America. A bill was introduced in the House of Representatives on 7 May called the 'Federal Food Irradiation Development and Control Act of 1984' (News Notes 1984). It had 4 main purposes, see Table 6.

1. To define irradiation as a process or treatment rather than as a food additive. This was a complete reversal of the original 1958 Act whereby irradiation was defined as an additive. That definition implied that treated food must in some way have
changed in composition and that some 'additive' had appeared. The second part of the bill is to provide for on-going research and development of food irradiation; presumably this implies a financial commitment by the government to re-activate a number of federally-owned irradiation facilities which were axed in the late seventies.


1. To define irradiation as a process/treatment rather than as a food additive.
2. To provide for on-going R & D in food irradiation.
3. To provide for leasing of government-owned sources of irradiation to private industry.
4. To establish a Joint Operating Committee (JOC) to,
   (1) Coordinate research findings.
   (2) Act as a liaison to promote consumer acceptance of irradiated food.
   (3) To promote private development.


The third part is an obvious extension of part (2) in that it states that the bill will provide explicit authority for the leasing of federally owned irradiation source materials to the private sector to ensure an adequate supply while ensuring federal safety and
transportation standards. The fourth part of the bill is to establish a Joint Operation Commission, made up of representatives of federal agencies and the public, which would co-ordinate research and information exchange efforts and act as a liaison to promote consumer acceptance of food irradiation and private development.

Thus the wheel, so to speak, has turned full circle and irradiation is up-graded to the position it should have been in the late fifties.
REFERENCES


