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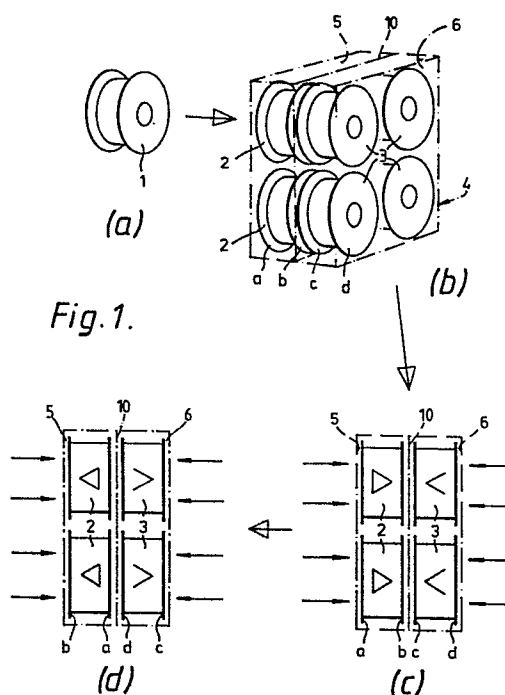
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64 **Gamma irradiation.**

67 To increase the efficiency of utilisation of radiation from a gamma source when irradiating discrete articles, they are first assembled in an array of such thickness that on irradiation on one face the dose received at half the thickness from that face is significantly less than half the dose adjacent that face and may be as little as one-quarter of that dose. The array is then irradiated equally on both faces, divided midway between those faces and re-assembled with those faces in contact with one another to form a new array which in its turn is irradiated from each of the two newly-exposed faces to the same exposure as before.



GAMMA IRRADIATION

This invention relates to the irradiation with gamma rays of discrete articles and especially of relatively dense articles that will absorb and/or scatter
5 a significant part of the radiation flux incident on them. A major application is in the radiation processing of coils of insulated wires and cables for the purpose of cross-linking the polymeric constituents thereof.

Gamma radiation for such purposes is in current
10 commercial practice obtained from Cobalt-60, usually in the form of metallic pellets enclosed in stainless steel tubes for convenience and safety in handling. Generally a source comprises a number of such tubes, of varying ages and therefore differing activities, set up in a plane
15 parallel array.

It will be apparent that such a source is not susceptible to any close control of the direction or even the local intensity of irradiation, and efficient utilisation of the source therefore depends upon careful
20 control of the positioning and movement of the articles to be irradiated.

Assuming that products are irradiated symmetrically on two opposite faces, the maximum dose ratio Z between parts of the product can, as a first
25 approximation, be given as:-

$$Z = \frac{D_o}{D_c} = \cosh (PTR/2) \quad (1)$$

where D_o = dose at outer (irradiated) surfaces
 D_c = dose mid way between those surfaces
 (which is also the minimum dose)
 P = absorption constant (m^2/kg)
 5 T = thickness between faces (m).
 R = mean density of product (kg/m^3)

We have found experimentally that for products of reasonably uniform density a sufficiently close estimate of Z can be obtained by using the value:-

$$10 \quad P = 0.0055 \, m^2/kg \quad (2)$$

When the product is irradiated on one face in this manner then, as a first approximation the magnitude of the radiation flux passing through the opposite face is F where:-

$$15 \quad F = F_o / \exp (PTR) \quad (3)$$

Consequently the efficiency E of absorption of energy within the product is given approximately by:-

$$E = (F_o - F) / F_o = (1 - \exp (-PTR))$$

$$20 \quad \text{or} \quad E = \left(1 - \frac{1}{\exp (PTR)} \right) \quad (4)$$

Therefore the efficiency improves as the product substance (TR) increases, that is, for a given product, as the thickness exposed to the radiation increases.

We have also discovered that using this process
 25 if the value of $Z = 1.25$ or less, then for all practical purposes the product can be taken to be uniformly irradiated. By re-arrangement of equation (1)

$$TR = 360 \cosh^{-1} (Z) \, Kg/m^2 \quad (5)$$

and substituting the value $Z = 1.25$ in (5) shows that the

limiting value for the product substance (TR) is then:

$$TR = 250 \text{ Kg/m}^2 \quad (6)$$

and the efficiency of absorption of the radiation is then,

$$\text{from (4): } E = (1 - 1/3.9) = 0.75 \quad (7)$$

In practice because of manufacturing and
5 customer requirements it is seldom possible or practical
to arrange that the product substance (TR) is exactly
equal to 250 kg/m^2 . Significantly greater values lead
to unacceptably high values for Z whereas lower values,
which are often the most convenient to use, lead to even
10 lower absorption efficiencies for the process.

We have now found that it is possible to improve
significantly the absorption efficiency of the process,
without a corresponding increase in the dose ratio (Z).

In accordance with the invention, the articles
15 are first assembled in an array of such thickness that on
irradiation on one face the dose received at half the
thickness from that face is significantly less than half
the dose adjacent that face and may be as little as one-
quarter of that dose. The array is then irradiated equally
20 on both faces, divided midway between those faces and re-
assembled with those faces in contact with one another to
form a new array which in its turn is irradiated from each
of the two newly-exposed faces to the same exposure as
before. (Doses are to be considered equal if their result
25 is substantially the same; as explained, for most purposes
total doses in a ratio between 1.25:1 and 1:1.25 may be
taken to be equal, though doses in individual radiation
passes will often need to be more closely equal; and

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although the division is preferably exactly on the mid plane, some displacement will be acceptable and may be necessary in some cases).

For a better understanding of the invention, it
5 will be further described, by way of example and illustration, with reference to the accompanying drawings in which Figure 1 is a flow diagram illustrating the principles of the invention and Figure 2 is a simplified diagram of a typical gamma-irradiation plant.

10 As shown in Figure 1, spools of insulated wire or other articles to be irradiated, reference 1, are assembled into an array (Figure 1 (b)) comprising layers 2 and 3 in a radiation-transparent package 4, which may for example be a box, a pair of boxes (one for each
15 layer), a multiplicity of boxes, or any other form appropriate to the material and form of the articles; boxes may be gas-tight tanks or any other suitable boxes; in particular they may be paper-board cartons used in conjunction with flexible container, as described and
20 claimed in another patent application in the name of BICC Public Limited Company filed on the same day as this application and claiming priority from British Application No. 8131144 filed 15 October, 1981.

As an aid to following the orientation of the
25 articles in subsequent steps, the flanges of one pair of spools is letter a, b, c, d respectively, and the outside faces of the array bear the references 5 and 6 respectively.

Figure 1 (c) shows the array from the front as

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it first approaches the irradiation zone following the route designated 7 in Figure 2. This takes the array past the radiation source 8 (comprising a number of tubes 9 filled with pellets of an appropriate radioactive material) so that the array 4 is first irradiated on the face 6. The array 4 then advances, without change of orientation, round the end of the source 8 and back along the other side of it, so that the array is now irradiated for a second time but on the opposite face 5.

10 In accordance with the invention (Figure 1 (d)) the array is split and its layers 2 and 3 are each reversed in orientation, without changing places, so that flanges b and c, which were previously adjacent one another and close to the mid-plane 10 of the array, are
15 now presented at the faces 5 and 6 respectively of the array, and the re-formed array is again passed along the path 7 (Figure 2) for further irradiation.

The initial radiation dose at the mid-plane (10 in the illustration), resulting from the first irradiation
20 on the first face (6) of the array is preferably in the range 0.4 down to 0.25 of that adjacent to this face. Taking the extreme case where it is 0.25, then from equation (3):

$$(TR/2) = 250 \text{ kg/m}^2$$

25 (Taking $P = 0.0055 \text{ m}^2/\text{kg}$)

where $(TR/2)$ is half of the product substance presented to the radiation. Since the product array presents a total substance path $TR = 500 \text{ kg/m}^2$ it can be seen from equation (4), that the nett efficiency of the process will

then be $E = 0.94$

Because of the symmetrical radiation process the dose ratio Z within the product will still be 1.25 and the same as if an array of one half of the thickness had been
5 irradiated on two opposite sides without splitting.

Assuming each irradiation produces unit dose on the outer face of the array upon which it is incident the doses within the splittable array at each step would be as follows:

10	Distance from face (6) first irradiated	0	T/4	T/2	3T/4	T
	1st	1.00	0.50	0.25	0.125	0.063
	2nd	1.063	0.63	0.50	0.63	1.063
15	3rd	1.50	1.13	1.31	0.755	0.56
	4th	1.56	1.25	1.56	1.25	1.56

so that $Z = 1.56/1.25 = 1.25$

Example 1

A PVC insulated copper equipment wire has a
20 solid conductor 0.6 mm diameter and radial insulation
thickness 0.25mm (overall diameter 1.10 mm), so that the
mean density of the insulated wire is 3307 kg/m^3 . This
is wound on a cardboard reel, the width of winding between
flanges being 0.067 m and the substance path through the
25 flanges being negligible. The wound density of the wire D
is 2150 kg/m^3 and so the product substance path (flange
to flange) is $0.0067 \times 2150 = 144 \text{ kg/m}^2$.

Irradiation was conducted with the spools in pairs, flange to flange, to make up a product package two

spools thick, giving a substance path of $2 \times 144 = 288 \text{ kg/m}^2$, too high for the conventional technique. The array was processed in accordance with the invention, and the incremental dose at the mid-plane of the array source in each pass being about 0.4 that at the face nearest the radiation source. In the first irradiation on each side of the package, the dose adjacent to each of the flanges was measured and found to be about 2.94 and 2.89 Mrad respectively, whereas the dose at the centre flanges was found to be 2.30 Mrad. In the second irradiation, the corresponding measurements were (outer) 2.92 and 2.95 Mrad, and (centre) 2.33 Mrad. The nett result was therefore that all spool flange positions received a practically equivalent dose of about $2.93 + 2.31 = 5.24$ Mrad. The estimated ratio of maximum to minimum dose within an individual reel winding, as given by (1) is:

$$Z = \cosh (144 \times 0.0055/2) = 1.08$$

which is in good agreement with the experimentally observed value of:

$$(2.93 + 2.31)/2 \times 2.31 = 1.13$$

The absorption efficiency for the package was, from equation (4):

$$E = [1 - 1/\exp (0.0055 \times 2 \times 0.067 \times 2150)] = 0.79$$

For a package of single spool thickness Z would have been the same but the efficiency would have been reduced to 0.54. Using the method of the invention in this particular case increases the efficiency by about 50 per cent.

Example 2

A twin jumper wire has the following dimensions:

Conductor 1/0.5 mm copper

Insulation 0.3 mm radial PVC

5 Linear density of a twisted pair = 5.6 kg/km

Winding density on reel = 1400 kg/m³

Width of winding
(flange to flange) = 0.071 m.

10 Product substance path
per spool = 1400 x 0.071 = 100 kg/m²

Because of the low value of product substance path per spool it is possible to place two spools flange to flange and to consider these as a single entity having an effective substance path = 200 kg/m² which is still less
15 than the optimum value of 250 kg/m², which would give a value of $Z = 1.25$ for conventional processing.

The array formed therefore comprises two halves each containing a pair of spools. The total substance path of the array is:

20 $TR = 4 \times 0.071 \times 1400 = 400 \text{ kg/m}^2$

The ratio of the incremental dose received in one pass at the mid-plane of the array to that nearest the radiation source was about 0.33.

After the first half of the process and before
25 splitting and re-assembling the package the mean doses measured through the package were:

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Outer flanges 2.78 Mrad

Adjacent flanges at quarter
and three-quarter
positions of the array 1.75 Mrad

5 Centre of array 1.60 Mrad

On completion of the process the doses were
therefore: for the flanges irradiated at the centre and
outer positions, $2.78 + 1.6 = 4.38$ Mrad; and for the
flanges irradiated in the quarter and three-quarter
positions, $2 \times 1.75 = 3.5$ Mrad. Consequently the ratio of
10 maximum to minimum dose was:

$$Z = 4.38/3.5 = 1.25$$

which was also the dose ratio across the winding on
individual spools.

15 From (4) the efficiency of the process in
accordance with the invention is:

$$E = (1 - 1/\exp(0.0055 \times 400)) = 0.88$$

For this wire, had the array consisted of either
single spools, or paired spools, of the same size then the
20 absorption efficiencies in conventional processing would
have been 0.42 and 0.67 respectively and the dose ratios
(Z) 1.04 and 1.15 respectively.

Using the method of the invention in this case
improves the efficiency by about 100 per cent compared
25 with that obtainable on a single spool thickness package
and by about 31 per cent compared with that obtainable
with a double spool thickness package.

CLAIMS

1. A method of irradiating discrete articles with gamma rays in which the articles are first assembled in an array of such thickness that on irradiation on one face
5 the dose received at half the thickness from that face is significantly less than half the dose adjacent that face, but not substantially less than one quarter of that dose, the array is then irradiated equally on both faces, divided mid-way between those faces and re-assembled with
10 those faces in contact with one another to form a new array which in its turn is irradiated from each of the two newly exposed faces to the same exposure as before.
2. A method of irradiating coils of insulated wire or cable with gamma rays in which the coils are first
15 assembled in an array of such thickness that on irradiation on one face the dose received at half the thickness from that face is significantly less than half the dose adjacent that face, but not substantially less than one quarter of that dose, the array is then
20 irradiated equally on both faces, divided mid-way between those faces and re-assembled with those faces in contact with one another to form a new array which in its turn is irradiated from each of the two newly exposed faces to the same exposure as before.
- 25 3. A method as claimed in Claim 1 or Claim 2 in which the initial radiation dose at the mid-plane resulting from the first irradiation on the first face of the array is in the range 0.4 down to 0.25 of that adjacent to this face.

4. A method of irradiating PVC insulated equipment wire substantially as described with reference to Example 1.
5. A method of irradiating twin jumper wire substantially as described with reference to Example 2.
6. Wire, cable, or other articles irradiated by the method claimed in any one of the preceding claims.

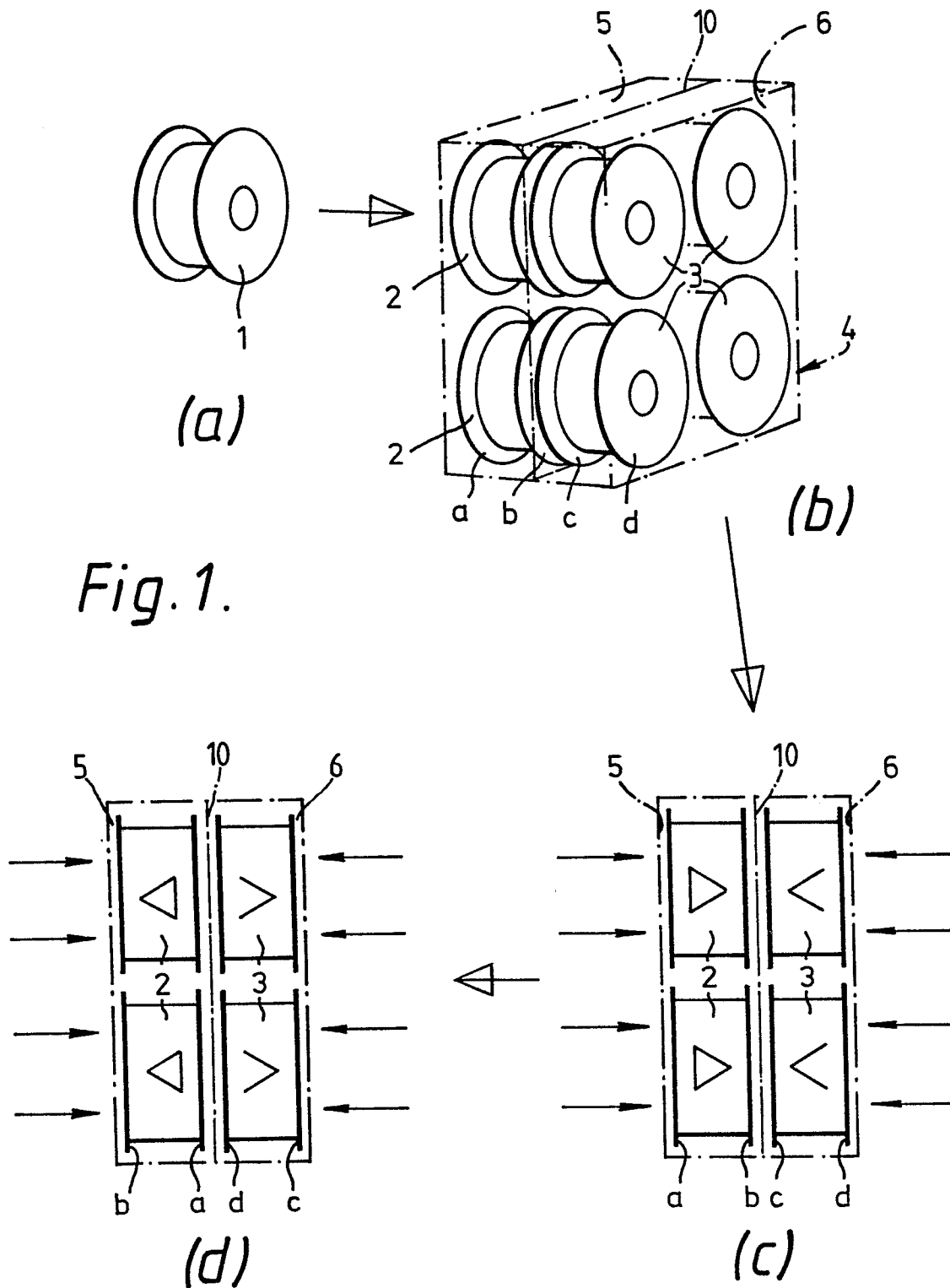
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Fig. 2.

