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Re-commissioning of an electron accelerator: industrial-type in research style

D.A.E. Ehlermann[a,]*, D. Morriseau[b]

[a] *Institute of Process Engineering, Federal Research Centre for Nutrition, Haid-und-Neu-Str.9, 76131, Karlsruhe, Germany*
[b] *Thomson-CSF-LINAC, Orsay, France*

Abstract

After 25 years of utilization in 1992, the electron linear accelerator was replaced by a modern type, CIRCE III of CGR-MeV (now Thomson-CSF). The goal had been to bring a typical industrial-style machine-source of radiation to the research institute in order to enable it to study any relevant parameter in radiation processing of food under commercial conditions. The machine should be as close in design to industrial practices, but at the same time allow for research into dosimetry and process control. As the FRCN moved to its new site, the decision was to re-install the accelerator there. At this occasion and based on the operating experiences of the recent years, several new features were introduced: the scan mode was changed from during-pulse to shot-by-shot; the bending magnet was modified from 107° to 253° (pretzel-type); the exploitable scanning width was increased from 40 to 80 cm. After this modification, the machine characteristics had to be verified. For the changed scan-mode the adjustment of pulse repetition rate, scan frequency, transport velocity, and beam cross-section in both directions, had to be established for the targeted low-dose treatments (about 100 Gy). Furthermore, the facility has now two separated beam-outlets, one for handling the prepacked materials on a transport system, the other one for bulk material handling (not yet installed) and for bremsstrahlung-mode experiments. First results with the accelerator after its transfer to the new site are reported; the radiation field characteristics after the modifications are given. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Since more than 50 years, the Federal Research Centre for Nutrition at Karlsruhe, Germany, is a focal point in food irradiation: It operated several radiation sources and contributed to the knowledge of this technology. Among the radiation sources were early X-ray machines, a Van-de-Graaf accelerator and a linear accelerator (LINAC). There was always a preoccupation for machine sources over isotope facilities (Ehlermann, 1996; Ehlermann and Bauer, 1999; Gruenewald and Ehlermann, 1979). After more than 25 years of operation, in 1992 the LINAC for electrons (Varian, 6–22 MeV, about 10 kW at 12 MeV) had to be replaced because of the now obsolete construction and electronics. The choice was a then industrial-type of LINAC, the CIRCE III of CGR-MeV (now Thomson-CSF) (Gallien et al., 1985; Sadat, 1990). The goal had been to bring a typical industrial-style machine-source of radiation to the research institute in order to enable it to study any relevant parameter in radiation processing of food under commercial situations. The machine should be as close in design to industrial practices, but at the same time allow for research into dosimetry and process control. The same machine has been operating commercially since 1981 in France for the processing of mechanically deboned poultry meat (Gallien et al., 1983), which also was later on modified to CIRCE III (Sadat and Cuillandre, 1988). As the FRCN moved to its new site in 1998, the decision was to re-install the accelerator upon transfer. At this occasion and based on the recent operating experiences, several additional features were introduced which are not essential for industrial operation, but which allow for more detailed characterization of the radiation treatment.

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*Corresponding author. Tel.: +49-7247-82-3612; fax: +49-7247-22820.

E-mail address: diter.ehlermann@bfe.uni-karlsruhe.de (D.A.E. Ehlermann).

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2. General modifications

Several of such modifications are described here. The scan mode was changed from during-pulse to shot-by-shot; the bending magnet was modified from 107° to 253° (pretzel-type); the exploitable scanning width was increased from 40 to 80 cm; a system for individual pulse extraction was implemented (Fig. 1). After these modifications and the transfer, the machine characteristics had to be verified. The beam cross-section was reduced considerably because of the improved optical properties of the beam handling system. The energy spread in the beam was reduced as seen in the dispersion in the bending direction; however, the spectral distribution is still to be verified as the bending magnet (by the pretzel-principle) has achromatic properties. For the changed scan-mode the adjustments of pulse repetition rate, scan frequency and scanning width, transport velocity and beam cross-section on the goods in both directions had to be established again for the targeted treatments and also at low doses. Furthermore, the facility has now two separated beam outlets at identical beam handling properties, one for the standard handling of prepacked materials on a transport system with a sophisticated product tracking system, the other for bulk material handling (new system not yet installed) (Ehlermann, 1992; Ehlermann et al., 1985) and for bremsstrahlung-mode experiments. First results with the accelerator after its transfer to the new site are reported, the radiation field characteristics after several modifications are given below.

3. Verification of nominal electron energy

A pretzel-type or alpha-bending magnet has a rather homogeneous magnetic field and, hence, the radius of any trace of an electron on its path through the magnet is a measure of the particle energy. However, by the design of CIRCE III there is a certain dispersion of the particle energy, up to ±10% around the nominal beam energy. An independent measure of particle energy is the 'effective' beam energy, i.e. the energy a monoenergetic electron would have in order to resemble a depth dose curve closer to the practical depth dose curve (Fig. 2). For several media a relation between the depth R_{50} (at which the dose is 50% of the dose at the maximum) and the 'effective' electron energy has been established (ASTM, 2000). For three machine settings at 5.0, 7.5 and 10.0 MeV, the results are reasonable and acceptable (inset in Fig. 2).

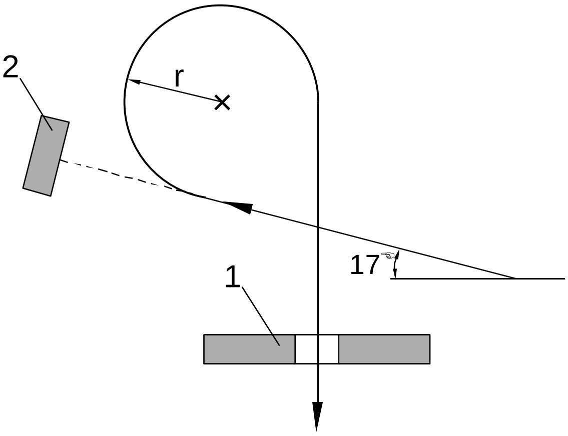

Fig. 1. Beam path through the 'pretzel'-magnet to the scanning magnet (1); in single-pulse mode the beam is absorbed in a beam-dump (2) and a pulse is extracted by activating the bending magnet.

4. Exploitable and equivalent scan-width vs. physical scan width

For the control of the physical settings of the accelerator, even the physical or geometrical course of the beam from the scanning magnet (in particular the virtual turning-point) and its relation to the trace of the beam on the goods is essential. For a given preset geometrical scanning width, depending on the distance to the goods and the dispersion of the beam-spot, there result certain useful ranges (Fig. 3). A general requirement for dose homogeneity in scan as well as in transport direction was ±5% variation or less; from the measured dose distribution over scan the 'exploitable' scanning width was derived and related to the nominal scan width setting (dashed vertical lines in Fig. 3). Similarly, an 'equivalent' scanning width can be derived, i.e. the width of a truly rectangular dose profile with the same area under it as under the practical profile (full vertical lines in Fig. 3) (ASTM, 2000).

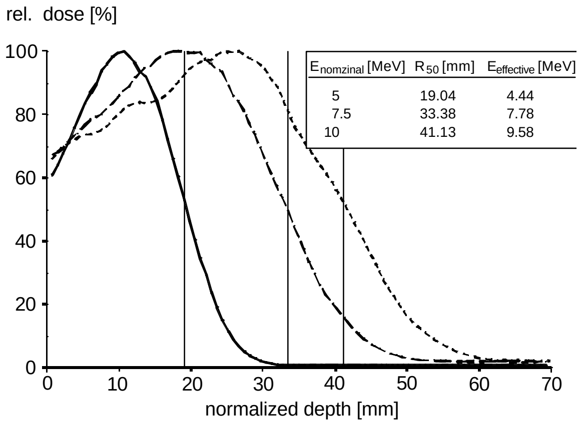

Fig. 2. Depth dose curves for 5.0, 7.5 and 10.0 MeV electrons in PVC; maximum dose normalized to 100% each; effective energy calculated according to ASTM E 1649 (ASTM, 2000).

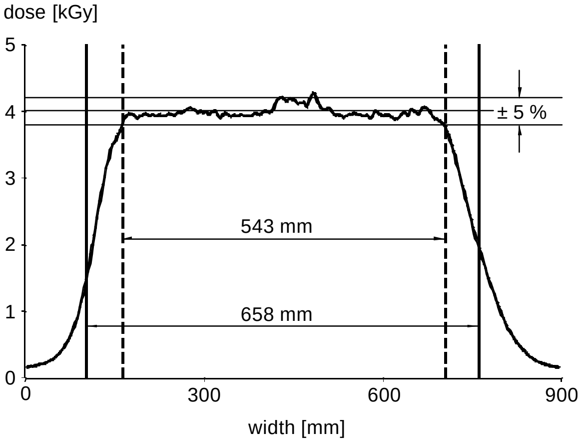

Fig. 3. Dose distribution over scan: ±5% zone around the average through the 'roof', vertical dotted lines mark exploitable width of 543 mm for a nominal setting of 600 mm; full lines mark a rectangle of equal area to the total area under the full dose distribution, i.e. the equivalent width.

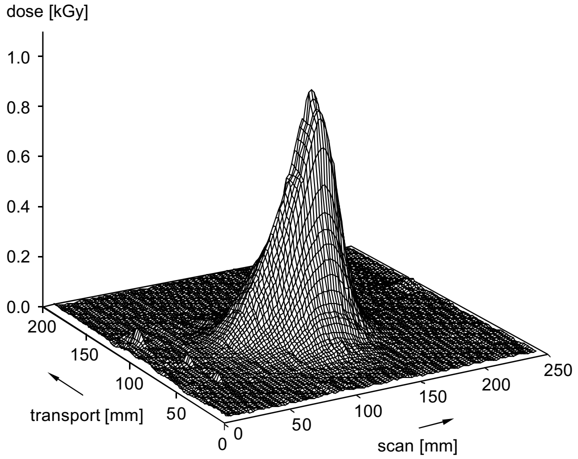

Fig. 4. 3D-plot of the dose distribution for a single pulse on the surface of the goods.

5. Single-pulse extraction

The individual pulse extraction system is a very unique feature: traditional LINAC for similar purposes could have a double pulse triggering: the first pulse loading the circuitry, the second one being the real shot, in order to achieve reproducibility of subsequent single pulses. The accelerator at Karlsruhe has now a completely unique approach: the LINAC is run at a lower frequency (about 10–50 Hz) at which pulse shapes are very stable, the sequence of pulses is absorbed in a beam stopper behind the bending magnet (Fig. 1). Individual, pre-programmed pulses are extracted by activating the bending magnet for the duration of the pulse. By this way, the cross-section in a single pulse may be measured using low-dose dosimetry films of suitably large dimensions (Fig. 4). From this dose distribution, a contour plot is derived (Fig. 5) which also shows the beam cross-section effective for harmonized overlap of subsequent pulses in the direction of scan as well as in the direction of good transport. This exercise was repeated for three machine settings at 5.0, 7.5 and 10.0 MeV. The single-pulse feature may also be used to characterize the physical scanning width by sending a pulse (or a series) to one extreme deflection of the scan, after this to the other extreme, as long as the beam exit window can tolerate the heat dissipation; by this approach less expensive, less sensitive dosimetry films can be used (e.g. PVC).

6. Low-dose processing

Another difficulty with high-power, industrial radiation sources is the availability of low-dose treatment: isotope facilities might reduce the amount of the radioactive source raised; however, industrial accelerators usually lack a specific circuitry to vary the 'load curve' in a wide range. Hence, there have been several approaches (McKeown et al., 1995), to dissipate the generated energy, contained in one pulse, over extended areas. Also CIRCE used originally the approach to scan each single pulse over the full width of scan. However, such systems never worked reliably in the low-dose range; homogeneity of dose in scan direction was always achieved at higher doses only with multiple overlap of subsequent pulses and scans, and hence by levelling-away of any fluctuations. This harmonized setting of pulse-repetition rate, scan frequency, scanning width and transport speed of the goods is determined from the beam cross-section on the surface of the goods (Fig. 5). At present, the accelerator at FRCN could be tuned at around 1 kGy for a dose range within ±5% over a scan of 80 cm on the surface of the goods. At present, the scanning systems operate in the zig-zag-mode, i.e. for homogeneity a double overlap of subsequent pulses is indispensable; however, as the scanning function is implemented in the software any shape can be programmed. This feature using forward scanning and fast fly back, hence, will allow to achieve doses of about 0.5 kGy or lower. It is intended to achieve the same homogeneity down to doses below 100 Gy which are needed in specific disinfestation and sprout-inhibition applications. For this purpose, the effective cross-section of the beam on the goods will be widened by a linear factor of about 3 in order to achieve an area-specific dose rate reduced by a factor of 10 or more.

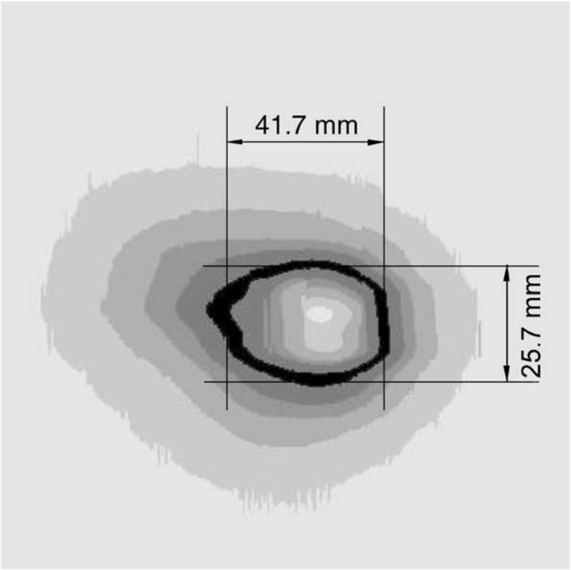

Fig. 5. Contour plot from Fig. 4 the 50% width is marked.

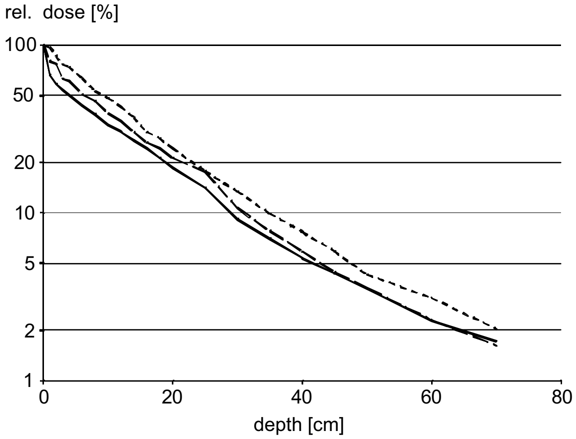

Fig. 6. Depth dose curves for bremsstrahlung in water: primary electron energy 5 MeV = full, 7.5 MeV is long-dash, and 10.0 MeV is short-dash lines.

7. Bremsstrahlung-mode applications

In addition, preliminary characterization of dose profiles in bremsstrahlung mode were measured and the exploitable scanning width (corresponding to Fig 3) determined. In order to derive exploitable thickness of goods to be treated, even depth dose curves for three machine settings at 5.0, 7.5 and 10.0 MeV were measured (Fig. 6). At 5.0 MeV, close to the surface, the initially steep decrease may result from a higher portion of the low-energy parts from the full spectrum. All three curves show 'beam hardening' in the depth of the goods as the profiles are not linear in this semi-logarithmic plot.

8. Summary

After its transfer to the new site of FRCN and implementation of additional features, the electron linear accelerator CIRCE III has been proven to be a reliable tool for research into industrial radiation processing of food. Its new features not required for industrial processing allow for the characterization of machine operation and for improvements in process control. Together width the new transport systems, the irradiation facility now allows for versatile and flexible processing with ionizing radiation.

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