

# Annual progress report. Accelerator Department. 1 January - 31 December 1976

**Research Establishment Risø, Roskilde**

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for the period 1 January 1976 - 31 December 1976.

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Abstract

A description is given of work in the fields of irradiation technology, chemical dosimetry, radiation chemistry, physical dosimetry and radiation bacteriology research, as well as of the operation of various irradiation facilities. Appendices include specifications of the irradiation facilities and one figure of the Risø 10 MeV linac facility.

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CONTENTS

## GENERAL INFORMATION

The objective of the Accelerator Department is to contribute to research, development, and the implementation of processes based on ionizing radiation; thus the following activities are carried out:

- Operation and maintenance of the irradiation facilities (three electron accelerators and three $^{60}Co$-units).
- Customer irradiation services for laboratories within and outside Risø, for hospitals, and for industry.
- Irradiation technology studies, including the upgrading of present facilities, development of new irradiation equipment, and improvement of equipment and methods for customer irradiation services.
- Design and construction of equipment for radiation experiments.
- Radiation chemistry research in relation to chemical dosimetry and pulse radiolysis of aqueous solutions connected with fundamental problems in chemistry. This research is carried out in close collaboration with the Risø Chemistry Department and with research groups in other countries.
- Radiation physics research in relation to systems used in dose calibration and dose distribution measurements.
- Radiation bacteriological research mainly in relation to radiation sterilization problems and radiation-resistant microorganisms, and also to increase basic knowledge of the radiation resistance mechanism.
- Production and supply of bacteriological standard preparations for control of irradiation sterilization plants.
- International collaboration on the subjects mentioned above, including participation in international meetings and working groups. Bilateral collaboration arrangements are maintained with a number of scientific laboratories in Europe and in the United States.

## REPORT ON THE ACTIVITIES

### 1. Operation and Maintenance of Irradiation Facilities[x)]

#### a. HRC Electron Linear Accelerator

By the beginning of the year the installation of the beam handling vacuum system had been completed and good vacuum established in the $10^{-7}$ Torr region. During the first three months of the year, beam control and measuring equipment for the all-over beam handling system was built and installed. During the period from May to December the total shut-down time for repair, maintenance and installation was about 1 month.

The old conveyor belt for product irradiation was modified and installed together with a new motor-driven section. A new gangway was built along the accelerator. This provides the necessary platform for repair and maintenance at the two meter high beam centerline. The master trigger generator controlling electron pulse length, pulse repetition rate, and external synchronization was modified and supplied with remote control. The pulse length of pulses in the nanosecond range can now be selected in fixed steps. Remote control is used for the pulse radiolysis equipment. Two aluminum beam output windows were designed and installed, one at the $45^{\circ}$ beam port in the accelerator room, and one at the straight-ahead beam port in the target room. In connection with the beam port in the accelerator room, a $\pm$ 0.5% beam slit and a small Faraday cup were designed. Equipment for control of the two switching magnets was designed and installed. In future all beam controls including scanning of the $90^{\circ}$ bent beam will be integrated into one control unit.

The first task was to establish the scanned beam for irradiation on the conveyor belt. The scanner window from the old 6 kW accelerator was used. By proper adjustment of the beam spot size, transient heating of the window material was minimized and ample margin against window damage was obtained for 10 kW average beam power. The scanner was adjusted to give a uniform dose along the scan, perpendicular to the moving direction of the conveyor belt. The homogeneity is within $\pm$ 5% along the 40 cm scan.

The dose control system for irradiation on the conveyor belt was calibrated by means of standard calorimeters, dye film and bacterial standard preparations. Routine irradiation on the conveyor belt was started in mid April.

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x) Technical specifications of the facilities are listed in Appendix 3.

The next task was to establish a beam in the target room. The beam can be adjusted along the centerline by means of the switching magnet SM 1 and the 90° bending magnet and focused by means of a triplet lens downstream of the beam tube. The influence of the triplet lens was found to be negligible due to an insufficient power supply; a new power supply will be constructed. Without focusing, the beam diameter at the straight-ahead window in the target room was measured to 10 mm. This beam spot size is suitable for pulse radiolysis experiments. About 25 percent of the beam current is lost in the beam handling system connecting the accelerator and the target room. Beam position monitors will be installed in the centerline to the target room and a better control of the beam is expected. A prototype beam position monitor was designed for this purpose.

The pulse radiolysis equipment from the old installation was reinstalled. With the exception of some modifications required for the connection to the new accelerator, the general specifications of the system are unchanged. As the beam parameters of the new accelerator differ from those of the old machine with respect to beam current and pulse length, the pulse radiolysis equipment will be modified in accordance with these new parameters. Routine pulse radiolysis experiments were started in June.

At the beginning of 1977 an interlock system and radiation detectors will be installed in the target room. This will make it possible to permit entrance to the target room during bent beam operation.

There were a few component failures during the year; the main repairs were as follows:

On two occasions the water-cooled collimator in the injector leaked in the welding between the water-cooled chamber and the vacuum system; new collimators covered by warranty were produced from HRC. A new type of all-brazed collimator has been constructed by HRC. This unit is on stand-by at HRC and will be forwarded on request.

A non-cooled collimator in the injector tilted as a result of inadequate fixing. A holder was designed in the department for the collimator and the problem seems solved.

Over a longer period the output power from the klystron driver generator slowly decreased due to instability. On instructions from HRC, the generator was tuned up to normal power level, but there is still insufficient stability and HRC has been asked to solve the problem. On several occasions water-leak problems arose with the pump for the accelerator heat exchanger. The pump

was replaced by a new one with an improved gasket. After running for a year, it was observed that the water in the cooling loops for the accelerator waveguide and the klystron contained an excess of corrosion products. Steps are being taken to ensure quality of the water.

The 18-year-old cooling tower for the primary cooling system is now corroded beyond repair, and a new tower will be installed in 1977.

b. Febetron, Field Emission Accelerator

The field emission accelerator was used for radiation chemistry and for Raman spectroscopy.

After two years of intensive use the accelerator was opened up for a general overhaul. Nine defective capacitor modules and 7 repaired modules were replaced by new modules, 3 that were repaired remained in the accelerator. New tie rods for the capacitor modules were purchased for installation at the next overhaul.

c. ICT, Low-Energy Accelerator

The low-energy accelerator was used for applied radiation chemistry studies and dose distribution studies. Operation was without trouble; utilization was low.

d. 10,000 Ci $^{60}$Co-Facility

The 10,000 Ci $^{60}$Co-facility was used for radiation research and for customer services. It further serves as a reference source for microbiological efficiency testing according to the IAEA's recommendations for the radiation sterilization of medical products.

e. 5,000 Ci $^{60}$Co-Facility

The 5,000 Ci $^{60}$Co-cell, presently located in the Control Department of "Statens Seruminstitut", Copenhagen, was used for bacteriological research.

f. 3,000 Ci $^{60}$Co-Facility

The 3,000 Ci $^{60}$Co-cell was used for research in radiation chemistry,

radiation bacteriology and customer services. There were occasional difficulties with the rotation mechanism due to dust and moisture in between the lead block and the source chamber. The problem was temporarily solved by cleaning with alcohol, but it can only be eradicated by a modification of the irradiation cell. This modification will be carried out when the source is next reloaded.

## 2. Irradiation Technology

Preliminary investigations on producing amorphous silicon from quartz were performed. Electron irradiation of quartz in a hydrogen atmosphere excites and ionizes the gas and quartz molecules, and silicon is produced by the diffusion of the oxygen molecules from the quartz. The experiments will be carried out in collaboration with "Laboratoriet for Elektriske halvledere", Technical University of Denmark.

Equipment for transient conductivity measurements was developed for detecting charged species formed in a solution. The equipment employs a low-voltage pulsed dc technique minimizing undesired electrode polarization and electrolysis.

An analyzing slit for electron beam energy measurements on the linear accelerator was constructed, and the switching magnet SM 1 in the beam handling system was calibrated. This calibration was made by activation analysis of copper, and the energy was determined by comparison to the known threshold value of the photoneutron effect of $Cu^{65}(\gamma,n)Cu^{64}$. Comparison was made with a measured electron range in an absorber and the known range-energy relation.

A report on the cold cathode work is almost finished and will be published at the beginning of 1977.

Microdosimetry investigations have not yet been commenced, but will be started in 1977.

Material was prepared for exhibitions where the applications of ionizing radiation were demonstrated.

A flash photolysis equipment was constructed using available parts. The flash lamp energy is $\sim$500 J and the time resolution $\sim$10 $\mu$s.

## 3. Chemical Dosimetry and Radiation Chemistry

Work within this area concerns:

- Performance of routine dosimetry in relation to irradiation experiments and customer irradiation services.
- Development and exploitation of chemical dosimetry systems.
- Radiation chemistry and pulse radiolysis research.

Radiation work concentrates on investigating the reaction mechanisms and kinetics of irradiated aqueous solutions with the purpose of obtaining a better understanding of the possibilities and limitations of the practical application of aqueous chemical dosimeters, and of contributing to radiation chemistry knowledge in general.

Radiation chemistry and pulse radiolysis research is carried out in collaboration with the Riso Chemistry Department; Hilbert Christensen, Studsvik, Sweden; Edwin Hart, Port Angeles, U.S.A.; Martin Fielden, Sutton, U.K.; N. Getoff, Vienna, Austria; and J. Sutherland, Brookhaven, U.S.A.

a. Routine Dosimetry Services

Routine dosimetry was carried out in connection with customer irradiation services and irradiation experiments.

b. Development of Chemical Dosimetry Systems.

A training programme was set up relating to all the dosimeter systems used in the department. It was successfully tested by Dr. R. Uribe during his 2-month stay in the department as an IAEA fellow.

In future this programme will be obligatory for IAEA fellows with dosimetry interests.

c. Radiation Chemistry

Work continued on the radical cations of the methylated benzenes in aqueous solution. The rate constant for the reaction of the cation with water was determined in neutral solution (the radical cation produced by $SO_4^{--}$) by measuring the distribution of the methylbenzyl radical and the OH adduct formed from the radical cation. Under the assumption that the methylbenzyl radical is formed at the same rate in neutral and moderately acid solutions, the rate for the water reaction can be derived. Another way to determine this rate is to follow the decay kinetics of the radical cation,

again assuming that the rate of the proton-splitting reaction to the methylbenzyl radical is the same in neutral as in acid solutions. The two sets of experiments agree very well and the rate constants, varying from $10^2$ to $10^9$, can be correlated with the ionization potential of the parent compound.

Another reaction of interest, the reaction with hydroxide ions, was studied in alkaline solution. This yields in all cases the corresponding OH adducts; the rate constants vary by two orders of magnitude and can only be determined for the higher methylated compounds. These rates can also be correlated with the ionization potential.

Work was extended to include another monologous series; ethyl-, isopropyl- and tert-butylbenzenes. Preliminary results show that the proton-splitting reaction from the α-position becomes faster for $-CH_3 < -CH_2CH_3 < -CH(CH_3)_2$, while this reaction does not occur from the β-position, thus tert-butylbenzene has a relatively stable radical cation.

Work on the anisole-water system was finished by determination of the rate of the reaction of the radical cation with $OH^-$ and $Fe^{++}$ as function of the ionic strength, which proved the unit positive charge of the species. Furthermore, the spectrum was measured of the products from the reaction with the solute and from the dimerization of the radical cation.

A pulse radiolysis study of N,N-dimethylaniline in aqueous solution showed the formation of N-methylanilinomethyl radicals and radical cations in the ratio 1 to 2. The precursor for the two radicals is the OH radical. The existence of an OH adduct of DMA was demonstrated using nanosecond time resolution. The adduct undergoes a dissociation to hydroxide ions and radical cations with a rate constant close to $10^7$ $s^{-1}$. Several other substituted DMA compounds were investigated with respect to this dissociation reaction.

Because this reaction seems to be general for OH adducts, and may explain the known uncatalyzed water elimination reaction from the OH adducts of phenols, hydroquinone, anilines and methylated benzenes, several other compounds were investigated with the purpose of showing that the rate constant for the dissociation depends on the ionization potential of the compounds. It has not yet been possible to prove that all water elimination reactions take place via the corresponding radical cation, but the correlation with the ionization potential indicates that kind of reaction.

Work continued on the reaction mechanism in oxygenated strong alkaline solutions. The $O_2^-$ decay seems to be of first order, even with ultra-pure NaOH. The $O_3^-$ also decays via a first-order reaction, and in the ultra-pure

NaOH there is a simultaneous build-up of a species with absorption around 250 nm. Work was started on computer simulation of the reactions in an attempt to explain the experimental results.

## 4. Physical Dosimetry

Work concerns physical problems relating to dosimetry and the applications of ionizing radiation.

Efforts concentrated on optical techniques (holography and interferometry), dye film dosimetry, and radiation technology.

Collaboration in this field is maintained with W.L. McLaughlin, National Bureau of Standards, U.S.A.

### a. Optical Techniques

Work on holography and interferometry was limited because of the installation of the new linear accelerator. An attempt was made, however, to use Raman spectroscopy to measure transient reaction heats in chemical reactions. However, the lack of a medium with strong Stoke and anti-Stoke lines has hitherto prevented any success.

### b. Dye Film Dosimetry

Work continued on the production of dye films. Two types of film are produced, one with polyvinyl butyral and one with polyvinyl chloride as host material.

The films were used to determine the beam parameters of the new linear accelerator, and in a study of dose distributions in wire insulation irradiated by the ICT-accelerator.

### c. Physical Dosimetry Service

Service was carried out in order to facilitate proper irradiation conditions for visiting experimenters; this included the guidance of students performing graduate work.

## 5. Radiation Bacteriology Research

Bacteriological research concerns the development and testing of radia-

tion sterilization processes, as well as advice and assistance on specific projects to prospective users of radiation sterilization. Research interests are concentrated on the mechanisms of radiation resistance.

a. Bacteriological Research Projects

A project was started on the bacterium Micrococcus radiodurans. M. radiodurans was chosen as a research object because it is among the most radiation resistant organisms known. The mechanisms to cope with radiation damage found in this bacterium can thus be considered the most proficient so far developed in biological systems. The prime target of radiation damage to a cell is known to be the genetic material, i.e. the DNA molecule(s) that constitutes the genome. On this basis, experiments were started to determine the amount of DNA per cell, as well as the complexity of the genome of M. radiodurans. Preliminary results indicate multiple gene copies in each cell, a state which could greatly increase the radiation resistance.

Another line of research explores the causes of radiation resistance in Acinetobacter calcoaceticus. The radiation-resistant mutants chosen for the study were obtained by 1) repeated exposure of the surviving cells to $\gamma$-irradiation, and 2) by similar repeated exposure to UV-irradiation. Mutants selected by method 1) show only half the increase in UV- as in $\gamma$-irradiation resistance. The mutants obtained by method 2) show an equal increase in $\gamma$- and UV-resistance. Mutants isolated as being sensitive to $\gamma$-radiation are sensitive to UV as well, whereas mutants sensitive to UV may retain the $\gamma$-radiation resistance of the wild type. These observations should be reconciled with ionizing radiation that produces multiple types of lesion in the biological material, while UV-light predominantly produces one type of damage. Thus the collection of mutants of A. calcoaceticus indicates that in this organism a decreased capacity to repair the damage produced by $\gamma$-irradiation also infers a decreased capacity to repair damage induced by UV-light. On the other hand, a decreased efficiency of UV repair systems does not necessarily influence $\gamma$-radiation resistance.

Preliminary experiments with mutagens suggest a correlation between $\gamma$-radiation resistance and nitrosoguanidine (NTG). This is consistent with the fact that both agents induce lesions of similar nature in DNA.

b. Production and Supply of Microbiological Standard Preparations and Biological Indicators

A new biological indicator for the control of the efficiency of radia-

tion sterilization was developed. The new indicator is a preparation of a naturally occurring radiation-resistant strain of Acinetobacter calcoaceticus, a non-spore-forming Gram negative bacterium, also used in some of the research projects (see above). The indicator has already been used to test one Danish radiation facility according to the IAEA recommendations for radiation sterilization of medical products (1967).

Two Danish and one Norwegian radiation facility were tested in 1976.

Further, the laboratory produced, supplied and assayed standard preparations of Streptococcus faecium, strain $A_2$1, Bacillus sphaericus, strain $C_1$A and Bacillus cereus, strain C1/1. Batches of test pieces of Bacillus sphaericus were sent to Hungary, and of Bacillus cereus to the U.S.A.

c. Customer Service for Hospitals, Research Laboratories and Industry

The following services were maintained:

- General consultation, irradiation of test specimens, evaluation of materials and packagings in relation to the introduction of new hospital equipment.
- irradiation of pharmaceutical materials and fodders in order to reduce the initial number of bacteria.

During the installation of the new accelerator, any items that could not be sterilized at the $^{60}$Co γ-plants were packed at Risø and sterilized at NUNCATOM.

d. Training under the United Nations Development Programme

A three-month fellowship was arranged by the IAEA for Mr. Abdalla El Kholi, a research assistant from the National Center of Radiation Technology, Cairo, Egypt. While at the laboratory, Mr. El Kholi received training in microbiological control methods in connection with radiation sterilization.

Appendix 1

## Staff of the Accelerator Department

31 December 1976

### Academic Staff

D. Berenstein
E. Bjergbakke
J. Fenger
M. Trier Hansen (from 1 April 1976)
J.W. Hansen
J. Holcman
B. Lynggård
A. Miller
K. Sehested

### Technical Staff

S. Bøjlund Andersen
M. Elm Andersen
K. Boysen
K. Christensen (from 1o May - 6 August 1976)
H. Corfitzen
I. Hansen
T. Johansen
E. Engholm Larsen
F. Larsen
I.M. Larsen
L. Nielsen
W. Nielsen
P. Broen Pedersen
K. Pejtersen
B. Thomsen
M. Wille

### Office Staff

E. Haugaard
R. Madsen

Consultants

Dr. E.A. Christensen, Chief Physician, Control Department, Staters Seruminstitut, Copenhagen.

Dr. E.J. Hart, Port Angeles, WA., U.S.A.

Dr. W.L. McLaughlin, X-Ray Physics Section, Center for Radiation Research, National Bureau of Standards, Washington, D.C., U.S.A.

Visiting Scientists

Dr. E.J. Hart, Port Angeles, WA., U.S.A. (16 January - 7 February 1976).

Dr. A. El Kholi, National Center of Radiation Technology, Atomic Energy Establishment, Cairo, Egypt. (IAEA fellowship, 5 February - 30 April 1976).

Dr. A Karadjov, Institute of Radiobiology and Radiation Hygiene, Sofia, Bulgaria. (IAEA fellowship, 9 February - 5 November 1976).

Dr. W.L. McLaughlin, National Bureau of Standards, Washington, D.C., U.S.A. (14 - 23 March and 17 - 24 November 1976).

Dr. S. Patel, Food Engineering Laboratory, US Army Natick Development Center, Natick, Mass., U.S.A. (IAEA fellowship, 21 - 23 March 1976).

Dr. M. Barić, Ruder Bosković Institute, Zagreb, Yugoslavia. (30 March 1976).

Dr. R. Uribe, Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Mexico. (14 May - 16 July 1976).

Drs. A. Beres, S. Hegyesi and J. Herbak, Hungary. (DANIDA, 24 - 28 May 1976).

Dr. J.D.W. deLind van Wijngaarden, Atomic Energy of Canada Limited, Ottawa, Canada. (25 June 1976).

Professor D. Meyerstein, Nuclear Research Centre - Negev, Beer-Sheva, Israel. (26 July 1976).

Mag.scient. J. Thomassen, Institutt for Atomenergi, Kjeller, Norge. (7 September 1976).

Dr. N. Diding, Apotekens Centrallaboratorium, Stockholm, Sweden. (28 September 1976).

Dr. A. Kowalski, Technical University Łodź, Poland. (4 - 8 October 1976).

Drs. A. Bewick and E. Fuller, Atomic Weapons Research Establishment, Aldermaston, Reading, England. (19 October 1976).

Dr. Svetlana Sabovljev, Boris Kidrić Institute of Nuclear Sciences, Vinča, Beograd, Yugoslavia. (IAEA, 1 November - ).

Professor L. Eberson, University of Lund, Sweden. (8 December 1976).

Professor I. Draganic and Dr. Z. Draganić, Boris Kidrić Institute of Nuclear Sciences, Vinča, Beograd, Yugoslavia. (9 December - ).

Appendix 2

## List of Publications

Accelerator Department Annual Progress Report. 1 January - 31 December 1975. Risø-M-1836 (1976).

E. Bjergbakke, Gaschromatographic Measurements of Oxygen in Aqueous Solutions. In: Measurement of Oxygen. Proceedings of an Interdisciplinary Symposium held at Odense University, Denmark, 26-27 September 1974. Edited by H. Degn, I. Balslev, and R. Brook. Elsevier Scientific Publishing Company, Amsterdam, Holland (1976).

E. Bjergbakke, K. Sehested and O. Lang Rasmussen, The Reaction Mechanism and Rate Constants in the Radiolysis of $Fe^{2+}$-$Cu^{2+}$ Solutions. Rad. Res. 66, 433-442 (1976).

E.A. Christensen, Report on Visit at Boris Kidrič Institute of Nuclear Sciences, Vinča, Beograd, Yugoslavia, 2-15 May, 1976. Project No. YUG/74/o25-o1, YUG/8C/o5. IAEA, Vienna, Austria.

M. Gohn, N. Getoff and E. Bjergbakke, Pulse Radiolysis of Adrenaline in Acid Aqueous Solutions. Int. J. Radiat. Phys. Chem., Vol. 8, pp. 533-538 (1976).

J. Holcman and K. Sehested, Anisole Radical Cation Reactions in Aqueous Solution. J. Phys. Chem., Vol. 8o, No. 4 (1976).

Jerzy Holcman and Knud Sehested, Dissociation of the OH Adduct of N,N-dimethylaniline in Aqueous Solution. Submitted to J. Phys. Chem. (1976).

Arne Miller and William L. McLaughlin, Holographic Measurements of Electron-beam Dose Distributions around Inhomogeneities in Water. Phys. Med. Biol., Vol. 21, No. 2, pp. 285-288 (1976).

K. Sehested, J. Holcman and E.J. Hart, Conversion of Hydroxycyclohexadienyl Radicals of Methylated Benzenes to Cation Radicals in Acid Media. Submitted to J. Phys. Chem. (1976).

N. Zevos and K. Sehested, Pulse Radiolysis of Aqueous Naphthalene Solutions. Submitted to JACS (1976).

### Conference Contributions

E. Bjergbakke, Determination of the Rate Constant for the Reaction $Cu^{+} + O_2 \rightarrow Cu^{++} + O_2^{-}$. Nordisk Förening för Strålningsforskning och Strålningsteknologi 5. möte, 9-11 februar 1976, Stockholm Sverige.

E.A. Christensen, Strålesterilisation af Fødevarer. Selskabet for Levnedsmiddelteknologi og -Hygiejne, "Sterile Levnedsmidler". Statens Levnedsmiddelinstitut, 29 september 1976.

E.A. Christensen, Radiation Resistance of Microorganisms and the Use of Microbiological Methods for Control on Radiation Sterilization of Medical Products. Boris Kidrič Institute of Nuclear Sciences, Vinča, Beograd, Yugoslavia, 24-30 October 1976.

Johnny Hansen, Course in Vacuum Technique (42 hours at Svaleholm, Risø) 1976.

J. Holcman, Pulse Radiolysis Study of Anisole Aqueous Solutions. Nordisk Förening för Strålningsforskning och Strålningsteknologi 5. möte, 9-11 februar 1976, Stockholm, Sverige.

J. Holcman, Radical Cations of Aromatic Hydrocarbons in Pulse Radiolysis of Water Solutions. Gordon Research Conference on Radical Ions, Brewster Academy, Wolfebero, New Hampshire, U.S.A., 5-9 July 1976.

J. Holcman, Radical Cations of Aromatic Hydrocarbons in Aqueous Solutions. Brookhaven National Laboratory, Upton, L.I., N.Y., U.S.A., 11 July 1976.

Dan Meyerstein, The Reactions of Aliphatic Radicals with Low Valent Metal Complexes. Risø, 26 July 1976.

Appendix 3

## Irradiation Facilities at the Accelerator Department

### Electron Accelerators

1. Linear Electron Accelerator, Haimson Research Corporation, Model HRC-712

Specifications:

| | |
|---|---|
| Electron energy | 1o MeV |
| Average electron current | 1 mA |
| Peak electron current at 1o MeV | 11oo mA |
| Pulse length, normal mode | 1 - 4 μs |
| Pulse length, short pulse mode | 1o - 1ooo ns |
| Pulse repetition rates | single pulses and 12.5, 25, 37.5, 5o, 1oo, 15o and 2oo pps |
| Energy spread | 78% of the beam current within a spread of ± 2.5% |

Pulse-to-pulse dose variation:

| | |
|---|---|
| a) within a pulse train, less than | 1.8% |
| b) for single pulses separated at 1o min. intervals, less than | 3% |

Electron pulse flatness over a 2 μs interval, better than ± 1%

Accelerator room beam facilities:

1. A bent beam with scan width of 4o cm providing a process irradiation capacity of 1ooo-15oo Mrad kg/hour.
2. A horizontal beam, full beam peak power, for electron and X-ray irradiation.
3. A horizontal beam, reduced beam power (12.5 pps) in connection with a ± o.5% beam slit.

Target room beam facilities:

1. Three horizontal beam ports, reduced beam power (12.5 pps).

2. **Field Emission Electron Accelerator, Febetron Model 705B**

Specifications:

| | |
|---|---|
| Electron Energy | 0.5 - 2.0 MeV |
| Peak electron current | 4000 A |
| Pulse length (electron mode) | 20 ns |

3. **Low-Energy Electron Accelerator, High Voltage Eng. Corp., Model EPS 400-IND**

Specifications:

| | |
|---|---|
| Electron energy | 400 keV |
| Electron current | 50 mA |
| Scan width | 120 cm |

The accelerator is provided with conveyors to permit pilot-plant irradiation.

## $^{6o}$Co-Facilities

### 1o,ooo Ci $^{6o}$Co-facility (built at Risø 1957)

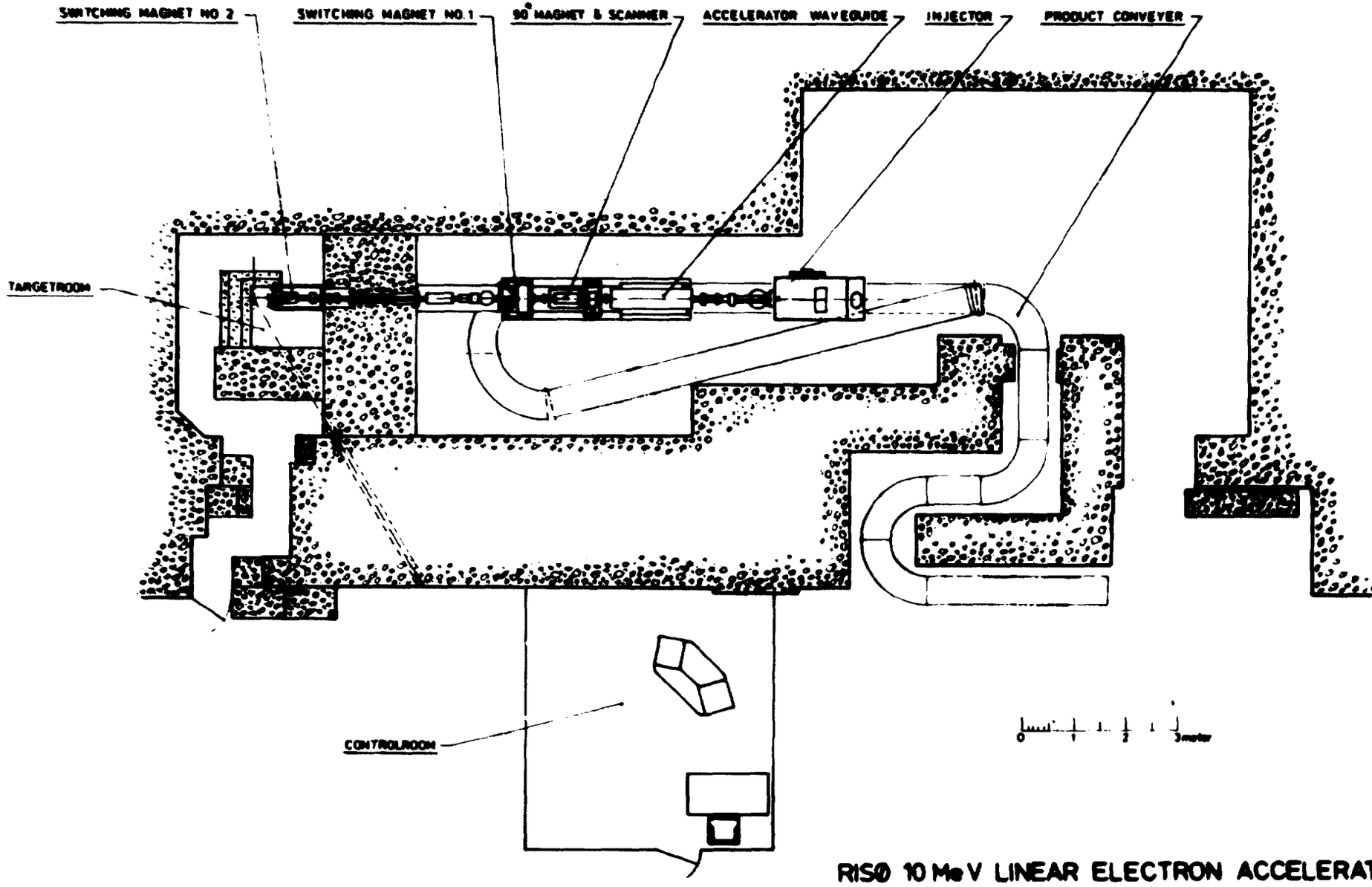
Designed for very homogeneous irradiation of samples with a maximum length of 1,ooo mm and diameters of maximum 18o, 1oo, or 6o mm. The corresponding maximum dose rates (7,ooo Ci,1 January 1977) are 3.8 x $1o^5$ rads/h, 1.oo x $1o^6$ rads/h, and 2.4 x $1o^6$ rads/h,respectively.

### 5,ooo Ci $^{6o}$Co-facility (built at Risø 1971)

Designed for laboratory use and fitted with a 123 $mm^ø$ x 15o mm irradiation chamber. The dose rate in the centre of the chamber (4,7oo Ci, 1 January 1977) is 4.o x $1o^5$ rads/h. The cell is located at the Control Department, Statens Seruminstitut, Copenhagen.

### 3,ooo Ci $^{6o}$Co-cell (built at Risø 1968)

Designed for laboratory use and fitted with a 12o $mm^ø$ x 2oo mm irradiation chamber. The dose rate in the centre of the chamber (2,2oo Ci, 1 January 1977, is 2.2 x $1o^5$ rads/h.




RISØ 10 MeV LINEAR ELECTRON ACCELERATOR

Appendix 6.