OEFZS--4732

The Seibersdorf TL Personnel Dosimetry Service

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November 1994

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Paper presented at the ISPRA-EUROCOURSE
"Techniques & Management of Personnel
Thermoluminescence Dosimetry Services"
Madrid, November 1994

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1. Introduction

Since 1976 the Department for Radiation Protection of the Austrian Research Centre Seibersdorf has been operating a TLD Personnel Monitoring Service, which presently covers about 18000 radiation workers in Austria, with monthly monitoring periods. We have been the first accredited monitoring service in Europe, which fully converted from film dosimetry to TLD. From the beginning up to 1991 the service was based on three automated TLD systems Model 2271 from HARSHAW, USA [1]. After extensive testing and comparisons [2], since almost four years now, the monitoring service has been operating on two HARSHAW 8800 systems, which are described in more detail below.

2. Description of the HARSHAW 8800 System used in our laboratory.

2.1. General Description

The TLD System 8800 workstation consists of the 8800 Card Reader and TLD Radiation Evaluation and Management Software (REMS) resident on a Personal Computer (PC). **Fig.1** is a block diagram of the system. The Card Reader has a total loading capacity of 1400 TLD cards, contained in 7 cartridges for up to 200 cards each. Up to four TLD elements can be read out simultaneously using a non-contact linear heating method is based on nitrogen gas. This heating technique improves the durability of the TLD cards, as compared by contact heating, in particular in view of low dose readings, and provides reproducible glow curves suitable for analysis and deconvolution algorithms.

2.2. 8800 Card Reader

The mechanical assembly of the reader consists of two carrousels, a loading and an unloading carrousel, holding 8 cartridges for up to 200 TLD cards each. A transport mechanism moves the from the loading carrousel through a read station to the unloading carrousel. In the read station the barcode identification number of the card is read and the TLD elements are heated. Up to four elements are simultaneously subjected to a nitrogen stream emitted by four jets on the end of thin copper tubings. The linear temperature profile is obtained by an electronically controlled DC current running through the tubes. With each readout the gas starts at room temperature and follows an adjustable linear temperature profile up to some 350 °C. The TL light emitted is converted to an electrical signal by a Photomultiplier tube (PMT) and transmitted to a µP-based data acquisition system.

If the reader can not interpret the card ID number, or other faults are detected during readout of one card, the card is moved to cartridge number 8 in the unloading carrousel, which is reserved for unprocessed cards. This is to insure against loss of data from reading cards without proper ID ore during any malfunction of the reader.

The complete operation of the reader is controlled by an internal host computer with operator console consisting of a full keyboard and monitor, positioned on the reader, using menu-driven software. The software architecture is that of a distributed processing system, in which the host computer directs the operations of the transport subsystem and each of the four Photronics subsystems, establishes and maintains communication with the TLD REMS on the external PC and supports the interface to the operator. A block diagram of the reader control system is shown in **Fig.2.**

The operator controls the mechanical operation of the card transport system through the internal host computer and the actual reading conditions (Time-Temperature-Profile, PMT Noise checks, calibration checks etc.) through the external REMS. Following our operating experience of about two years, the readers can be operated unattended during the night, without any critical problems.

2.3. Radiation Evaluation and Management System (REMS)

The REMS software package is installed in an external 386 type PC with at least 70 MB hard disk, MathCoprocessor , VGA monitor and matrix printer. An uniterruptible power supply for the complete workstation assures, that in case of power failure, the readout cycle is completed and the data acquired and stored on hard disk , before an automatic shutdown of the system is effected.

The data transmitted from the reader are monitored by the REMS software and stored for future reference, evaluation and reporting. It also stores information used by the reader in its operation, such as Time-Temperature-Profiles (TTPs) and individual calibration factors for the TLDs (Element Correction Coefficients EECs). The host computer of the reader and the REMS PC are interactive through the REMS software during all readout operations.

The REMS is menu-driven for all functions. The overall menu structure is shown in **Fig.3.** The main features are Quality Assurance Procedures (QA), Data Acquisition, Utilities and Computerized Glow curve Deconvolution (CGCD).

2.3.1. QA Procedures

The QA menu provides access to a number of subsystems, which establish, monitor and maintain the accuracy and operating parameters of the system.

- **"Daily QC"** controls the selection of the "Electronics QC", which initiates and displays a series of electronic measurements form the reader to determine, that the instrument is properly adjusted. This includes temperature at the heating jets, PMT high voltage, power supply voltages, reference voltage of the D/A conversion circuit, reference light, i.e. the output from a built-in reference light source and PMT noise. Lower and upper limits are set for each monitored parameter. Limits can be reset using a password.

- **"Reader Calibration"** provides access to the reader calibration screen, where information is entered which will be used in taking the data from a selected group of cards to generate the Reader Calibration Factors (RCF) for a Time Temperature Profile (TTP). The nominal dose for calibration cards (Nominal Irradiation Value), the calibration units, as well as the TTP number, are entered.

- **"Card Calibration"** provides access to the Card Calibration Screen, where information is entered to establish individual TL element calibration factors (EECs) for a specific group of field cards.

- **"Generate Calibration Cards"** is used at set-up time intervals to create a group of calibration cards which will be used in calibrating the reader on an ongoing basis. Its basic function is to create ECCs using an uncalibrated reader. In our system we use only calibration cards, which are exposed with ^{137}Cs in the circular exposure system of our dosimetry laboratory, as described below.

2.3.2. Data Acquisition

The Data Acquisition menu provides access for selecting the conditions under which the cards will be read, the data acquired, stored, reported and displayed.

- **"Time Temperature Profile"** is the screen where all the data necessary to establish the preheat, read and anneal temperatures and times are selected and displayed.

- **"Acquisition Set-up"** is where the operating conditions of the reader are selected and viewed. This includes PMT Noise and reference light check intervals, formats for record display, print and transmission, data storage conditions and threshold levels for various warnings.

- **"Read Cards"** is where the operator enters the group number and the TTP for each cartridge, specifies the function and initiates the read cycle.

2.3.3. Select Records for Processing

This function searches the data bases and generates collection of records which satisfy a set of user specified criteria. The user selects the data base, e.g. Field cards, calibration cards, environmental monitoring cards etc., and the group number. These records may then be further selected on date, Card ID, Personal ID, or exposure by element number. The selected data will appear on a selected records screen, from which additional selections may be made on a line-by-line basis. Records in the generated collection may then by displayed, printed, exported or sent to the mainframe computer.

2.3.4. Glow Curve Storage and Analysis

Although we do not use computerized glow curve analysis on a routine basis, all glow curves are stored for individual evaluation if required. In our experience glow curve analysis is most helpful to detect spurious or unexplained readings in the comparably low dose range between 0,5 mSv and 5 mSv, mainly caused by Chemiluminescence of non-radioactive contamination on the dosimeters. Without measuring and storing all glow curves, such very disturbing problems appearing form time to time, could not be identified and eliminated. Glow curves are also a most valuable proof in case of high dose readings.

3. Dosimeters

The TLD cards presently used in our dosimetry service are essentially the same, well known HARSHAW cards, as used before with the older Model 2271 readers, with the difference, that thinner LiF chips, vacuum packaged between PTFE-foils are used, to suit the requirements of hot gas heating. The cards, shown schematically in **Fig.4,** contain 2 or 3 LiF chips (1/8" x 1/8" x 0,015" or 0,0036" resp.) suspended between thin Teflon foils. For standard Beta/ Gamma dosimeters we use two LiF (TLD-100) chips, one with 0,015" thickness for penetrating, the other with 0,0036" for non-penetrating radiation. TLD-100 is used instead of the preferable neutron insensitive ^{7}LiF (TLD-700) for economic reasons. Our Neutron dosimeters contain three element cards with one additional ^{6}LiF (TLD-600) chip, sensitive to thermal neutrons. Here the two other chips are made from ^{7}LiF (TLD-700), which is insensitive to neutrons. For the ID number a LASER etched bar code is used.

Fig. 5 is a photograph of our TLD badge and the card, open and wrapped in the envelope. The badge contains the card in a plastics holder with one open window in front of the thin element (Position 2) and a filter of 600 mg/cm^2 in front of the thicker element (Position 3). The card is automatically wrapped in an envelope made from thin plastics foils, which is labelled with computer printed name, personal ID number and monitoring period. The wrapped cards are shipped to the customers, who insert them into our badges.

3.1 Dosimetric Performance

3.1.1. Dose Range, Linearity and Reproducibility

Fig. 6 shows the readout in the higher dose range between 10 mSv and 30 Sv. The response is linear with dose up to 2 Sv. The supra linearity ranges from 2 Sv up to 20 Sv. Above 30 Sv the reader starts to electronically saturate. In the low range the limit of detection, as defined by 3 sigma of the zero dose reading is about 20 µSv (without CGCD). The TL and instrument background of about 25 µSv is subtracted from each reading. Individual calibration factors, stored for each dosimeter card in the mainframe computer data bank, are used for all readouts.

The reproducibility of the readout in the low dose range at 0,1 mSv can be derived from **Fig. 7,** showing the readout of totally 70 dosimeters irradiated with 0,1 mSv. The standard deviation is about 4 µSv (4 %). For this readings the individual calibration factors have been applied.

3.1.2. Energy Response

The energy response of the dosimeters for measurement of Photon Dose Equivalent H_X - the present legal measuring quantity for photon radiation in Austria (and Germany) - is shown in **Fig.8,** in the energy range from 10 keV to 1,3 MeV. The solid curve with circles gives the readout of the filtered element (600 mg.cm^{-2}), the dotted curve with the empty triangles relates to the unfiltered elements. The (lower) dotted curve with the filled triangles give the ratio of filtered to unfiltered elements.

In order to fulfil the requirements of IEC standard 1066 [3], i.e. ± 30 % related to ^{137}Cs, the readout of the filtered element is used, if the ratio filtered to unfiltered is above 0,7. If it is below 0,7 the readout of the unfiltered element, multiplied with 0,8 is used. This way an energy response of ± 20 % is obtained, as can be seen from **Fig. 9.**

In 1995 the legal introduction of the new phantom related ICRU-quantity "Personal Dose Equivalent $H_p(d)$" is planned in Austria and Germany. Therefore extensive investigations have been performed in our laboratory [4] to check the suitability of our dosimeters for measurement of H_p. It has been shown, that for $H_p(10)$ and $H_p(0{,}07)$, energy- and directional response of our dosimeters fulfil the required specifications, if calibrated on the surface of a standard plexi (PMMA) slab phantom (30 x 30 x 15 cm^3), as recommended in the ICRU Report 47 (1992), and conversion factors between exposure or air Kerma and $H_p(d)$ for TE slab phantoms given in the IEC standard 1066 are used.

3.1.3. Directional Response

The directional response of our dosimeters measured, according to the standard requirements in the low energy range (ISO Standard Quality A40, eff. Energy 33 keV), for radiation incidence between ± 60° is shown in **Fig.10** for vertical rotation and **Fig.11** for horizontal rotation resp.

4. Dosimeter Handling and Evaluation Procedure

The complete monthly issuing and evaluation scheme essentially consists of the following steps.

- **New TLDs,** received from Harshaw, are first subjected to an acceptance test. Firstly the TLDs are read out, then exposed to a reference dose of 5 mSv, using our fast automated TLD Calibration System [9]. It is based on a circular exposure arrangement with ^{137}Cs sources in 1 m distance from the TLDs. **Fig. 12** is a schematic view of the calibration system, consisting of a shielded source storage container for selection of four radiation sources and a remote circular exposure set-up. The sources are transported by a pneumatic rabbit system. Up to 200 Cards can be exposed simultaneously within 5 min with a reproducibility of 0,5 % (2 sigma). The acceptance limit is a variation in sensitivity of max. ± 20 % as compared to the mean value of the previous cards. At this time the individual calibration factor is determined for each element. The test includes a check for redundant or non-applicable ID numbers. TLDs outside of specification (± 20% variation in sensitivity) are returned to the manufacturer.

- **Incoming TLD Handling:** The TLDs received from the customers by mail, first run through a contamination check on a conveyor belt. Bookkeeping of is done automatically by processing the cards through a bar code reader. Beta/Gamma- and Neutron cards are separated at this step. The bookkeeping system identifies and lists missing dosimeters, the lists are sent to the relevant customers with the next month dosimeters.

- **Readout:** The cards, filled in cartridges of up to 200 cards each, are externally preheated in an precision temperature controlled oven for 20 min at 100°C. Each cartridge contains 5 background / reference light check cards and 5 calibration cards exposed to 5 mSv in the circular exposure system. During readout of each element the TTP and the glow curve is displayed on the monitor. The cards are processed through the reader, stapled in cartridges and stored in a lead-lined safe for the next use. For our present workload of some 18000 dosimeters per month, two 8800 reader systems, shown in **Fig.13**, are used simultaneously. Before the end of each working day the readers are filled with 1400 cards each for unattended processing during the night. Cards which show any problems with ID readability etc. are stored in the separate cartridge and checked the next morning. All incoming dosimeters are processed during the first two weeks of each month. The readout values obtained from the REMS software, all glow curves, TTPs and operating parameters are stored on hard disk and simultaneously on optical disks (WORMs) for further processing by the mainframe computer.

- **Dose calculation and reporting:** After the deadline on the15th of each month the readout data, stored on optical disk, are transferred to the mainframe computer (DEC VAX cluster). The algorithm used for final dose calculation is shown in the flow chart **Fig. 14**. Depending on the leading digit of the ID number the data sets are identified as calibration-, regular Beta/Gamma-, or Neutron cards. At first each readout value (m) from the REMS protocol is multiplied with the individual element calibration factor (k_i), recalled from the data bank, and the mean background reading (≈ 0,025 mSv) subtracted, to achieve the individual readout value (a). The reader calibration factors (fe_1, fe_2, fe_3) are then calculated form the average readings of the 5 calibration cards as the ratio of the reference dose H_x and the average readout of filtered and unfiltered elements (A2 and A3). The readouts of Beta /Gamma-cards are then multiplied with the calibration factors (fe_2 and fe_3) to determine the corrected detector reading (TL2 and TL3). Now the ratio (R) of TL2/TL3 is taken. If R > 0,7 (penetrating radiation only) the dose value (D) is reported as the value of TL2. If the ratio R < 0,7 (non-penetrating radiation) the dose value (D) is taken as the corrected reading of the unfiltered element (TL3) multiplied with the factor 0,8. If D > 0,5 mSv and R < 0,8 the penetrating component (H) and non-penetrating component (W) are reported as a percentage of the total dose (D), whereby H = R and W = 1 - R (in %). For neutron dosimeters the difference (DIF) between the corrected reading of element 1 (TL1) and element 2 (TL2) is taken. If DIF> 0,5 mSv the neutron dose is reported as the value of DIF. The penetrating and non-penetrating dose values are taken from the readout of element 2 and 3 as explained before. Finally the resulting dose values (in units of mSv) are assigned to the monitored person using the personal ID file in our central dose registry. Then the dose reports, containing monthly, quarterly, annual and life-time doses are printed on special forms. Excess of legal dose limits is monitored and indicated on the form. It should be pointed out here, that any high dose readings above 5 mSv observed during the original readout of the incoming cards immediately stop the 8800 reader systems and alert the operator. In case of excess of legal dose limits the monitored person is identified via computer terminal and immediately notified. The dose reports are duplicated on computer-output-microfilm (COM) for permanent storage and easy access.

- **Automated wrapping of TLD cards and assignment for next month:**

  Fig. 15 is a photograph of the horizontal flow-wrap machine (ILAPAK, Model "Prima Super"), used for automated wrapping of the TLD cards. It consists of a conveyor chain, carrying the TLD cards through rotary crimp jaws, which wrap and seal the cards in a special packaging foil, coming from a role on a reel mount above the conveyor. The foil is a "hot-seal-sandwich" type, with a total area weight of 5 mg.cm^{-2} Plastic (PET) and 1,5 mg.cm^{-2} Al.

  On the (left) infeed side of the conveyor the TLD cards are stored in cartridges and continuously fed to the conveyor with a speed of one card per second. First the barcode of each card is read and entered in the controlling PC. The computer contains a list of all ID numbers of the individuals to be monitored and assigns the relevant TLD number from the barcode reader to the ID number of the individual. Before wrapping the ID number, name, monitoring period and TLD number are printed on the foil by a computer controlled Thermotransfer-Label-Printer. The printing colour is changed monthly for easy distinguishing between different monitoring periods. After wrapping the printed ID number (barcode) is checked again by the computer and the wrapped TLD stored in a second output cartridge. In case of any kind of failure (unreadable barcode, double number, unsuitable printing etc.) the TLD is automatically dropped in a separate "reject" cartridge. With this wrapping machine all 18000 TLDs can be wrapped ready for mailing within one working day.

- **Statistical evaluation and invoicing:** At the end of each year automatic invoicing is performed depending on the number of dosimeters used by the customer. In case of late returns (after the 15th of the following month) the customer is charged with an additional fee until the TLD comes back to us. For invoicing computer tapes are generated for printout of invoices and accounting. Finally statistical evaluations on the occupational exposure, separated in different branches, dose distribution histographs, frequency of dose limit excess etc. are annually derived from the central dose registry. **Fig. 16** is an example of a statistical evaluation, showing the average annual dose values obtained during the last 13 years. It can be clearly seen, that there is a trend towards lower annual doses with radiation workers in industry showing somewhat higher values as compared to medicine.

5. References

[1] Duftschmid K. E., *The Automated/computerized TLD-Personnel Monitoring System in Austria,* Nucl. Instr. Methods **175**, 162 - 165 (1980)

[2] Duftschmid K. E., *Automated TLD-Systems: What can we expect from the market today?* Radiat. Prot. Dosim. 34(1-4) 339 (1988)

[3] IEC Standard 1066, *Thermoluminescence Dosimetry Systems for Personal and Environmental monitoring,* (1991)

[4] Hua Jin, Duftschmid, K.E., Strachotinsky Ch. *Investigation of a New LiF TLD Individual Dosimeter for Measuring Personal Dose Equivalent $H_p(d)$ on different Phantoms.* Radiat. Prot. Dosim. 51(3)201 (1994)

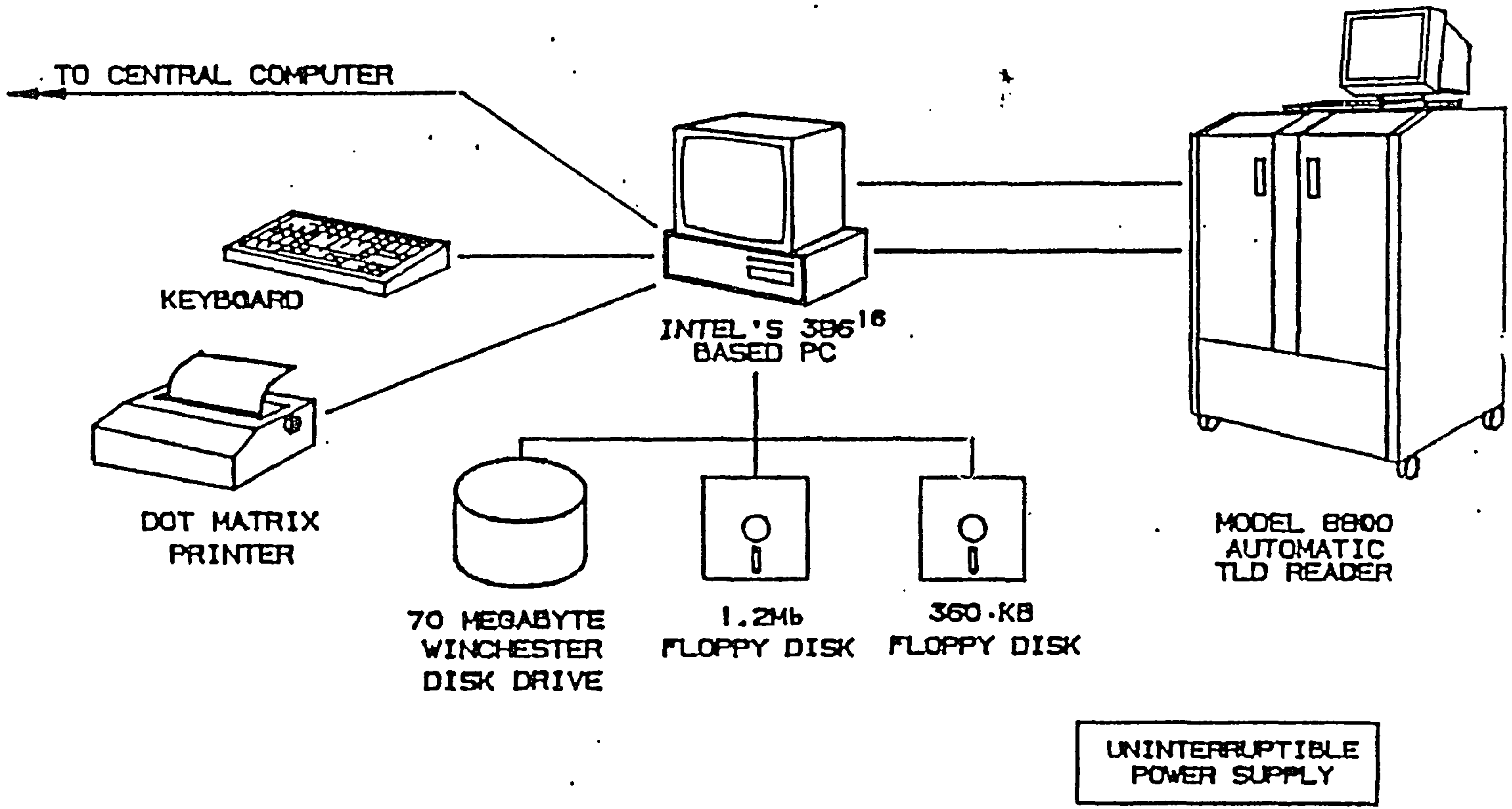

Fig. 1: TLD System 8800 - Workstation

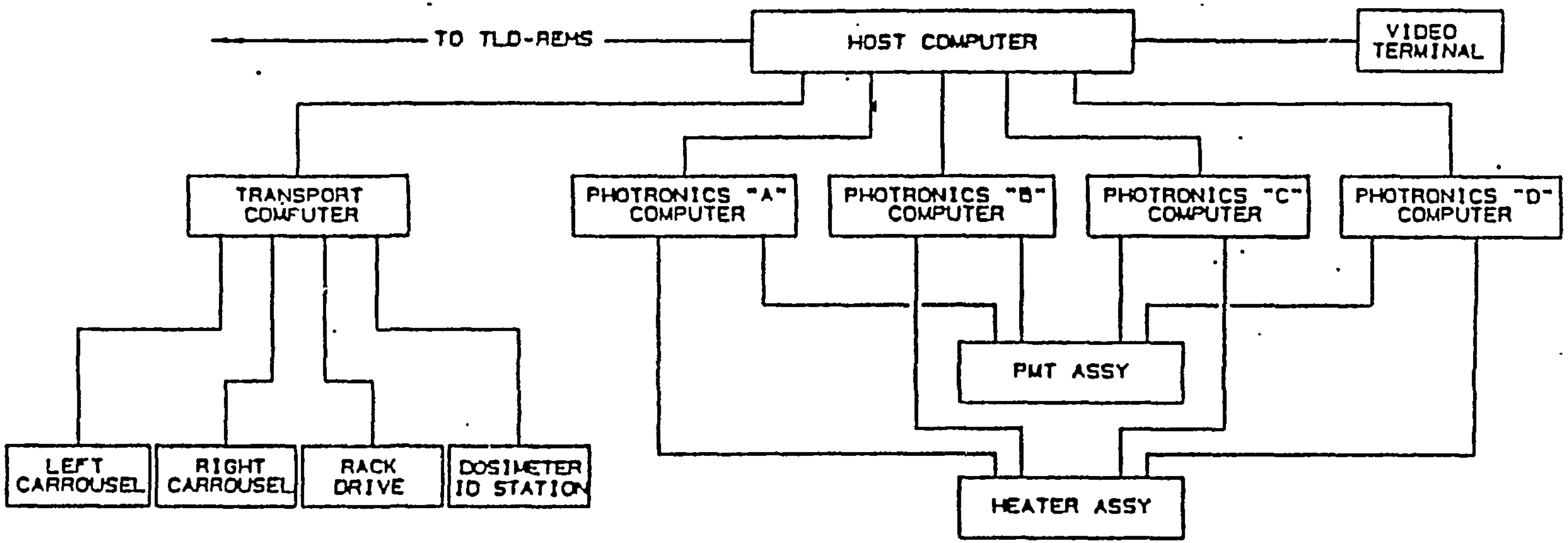

Fig. 2: Card Reader Block Diagram

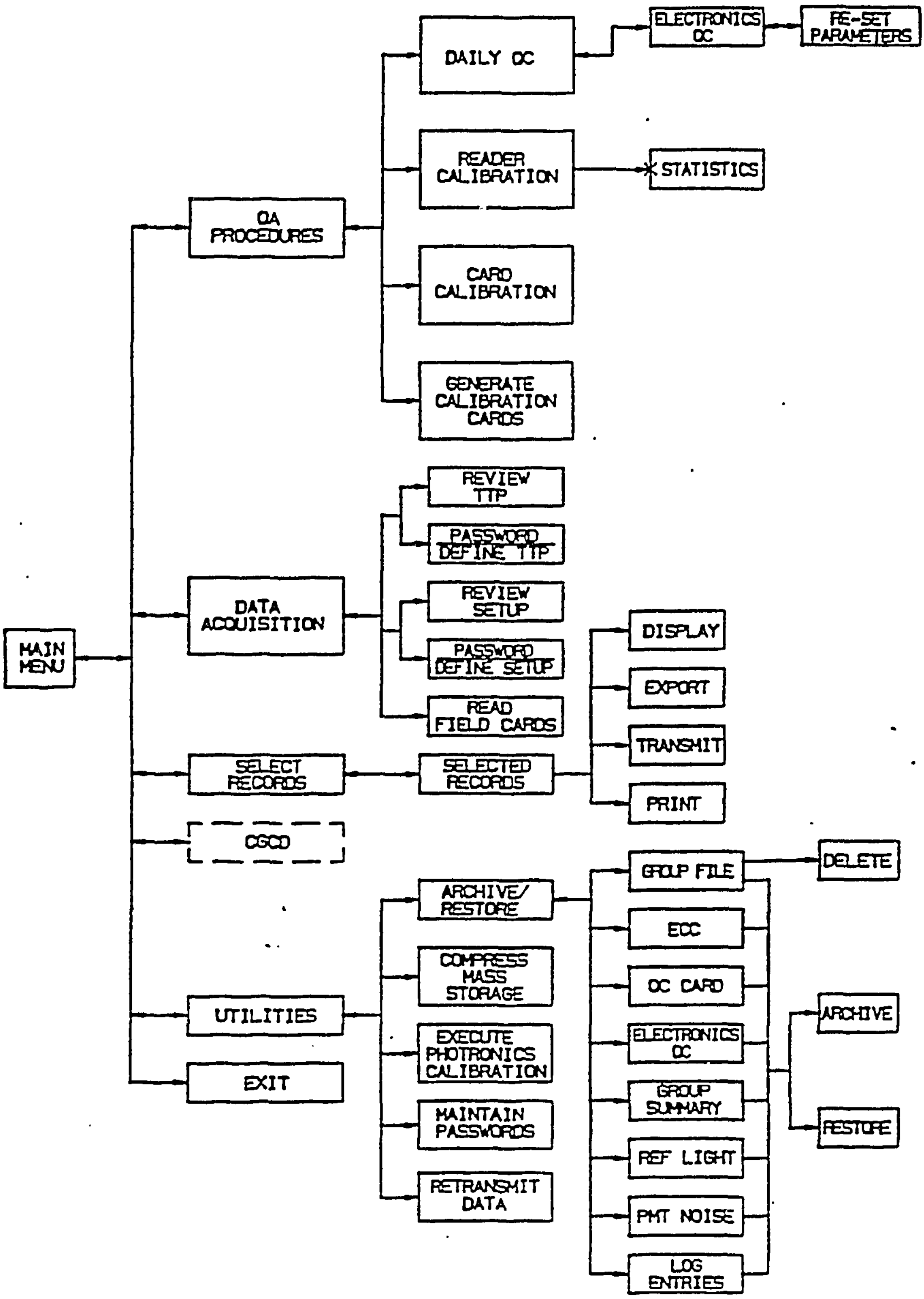

Fig. 3: Menu Structure

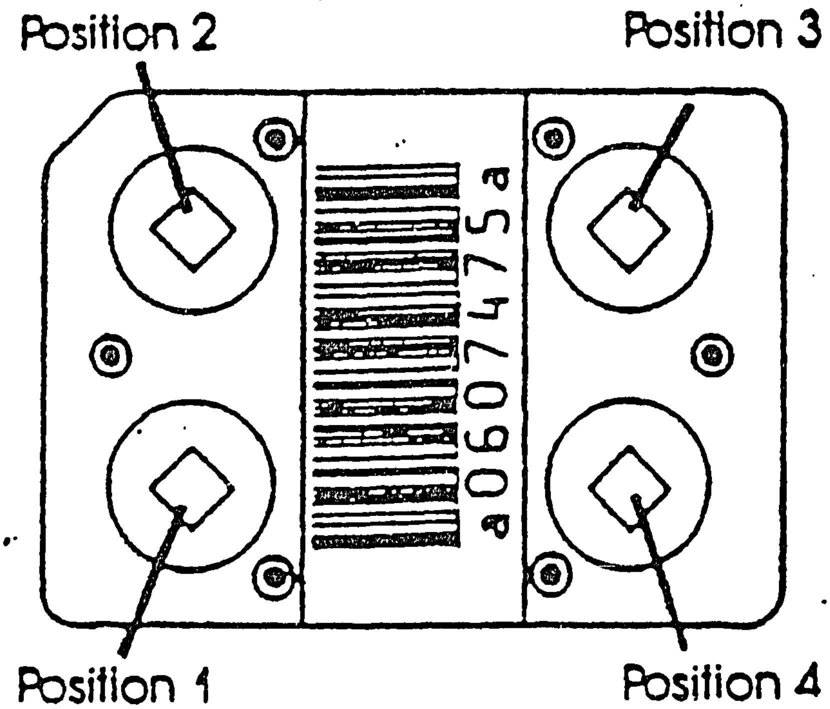

Fig. 4: Schematic View of 4 Element Card

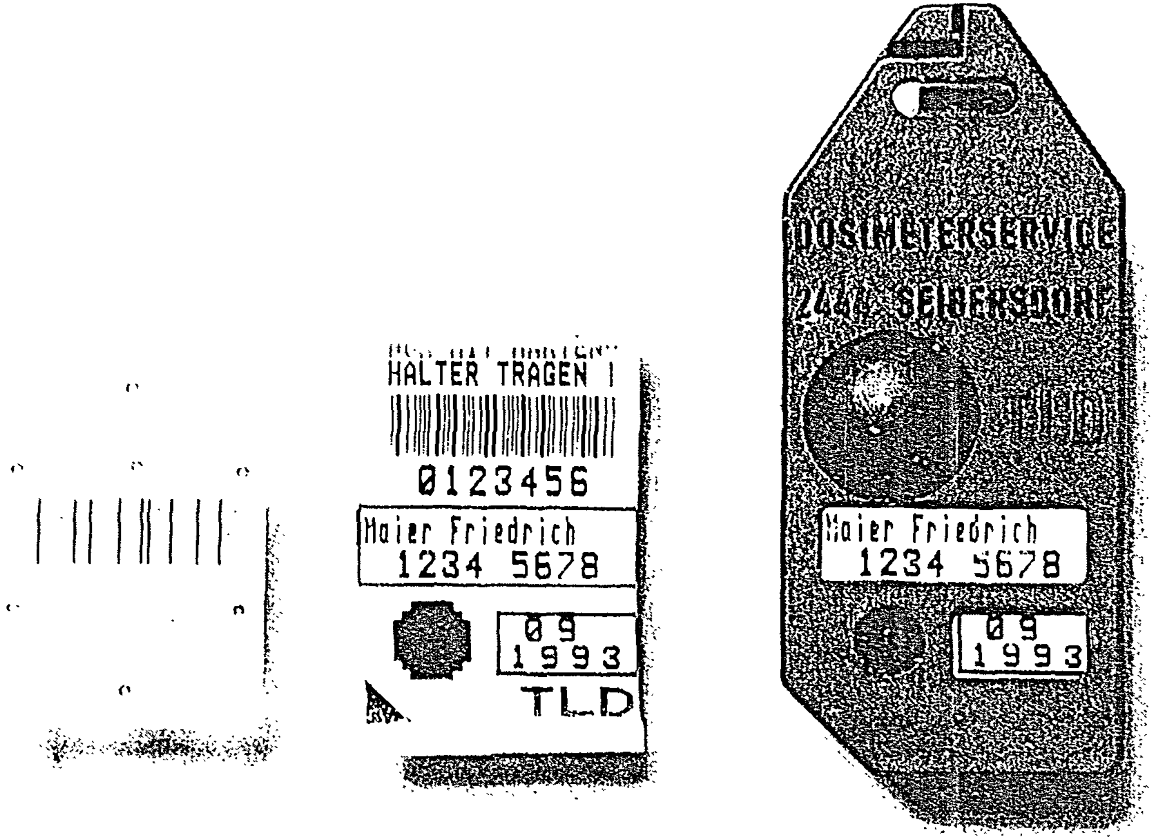

Fig. 5: The Seibersdorf TLD badge with Dosimeter Card wrapped in the foil

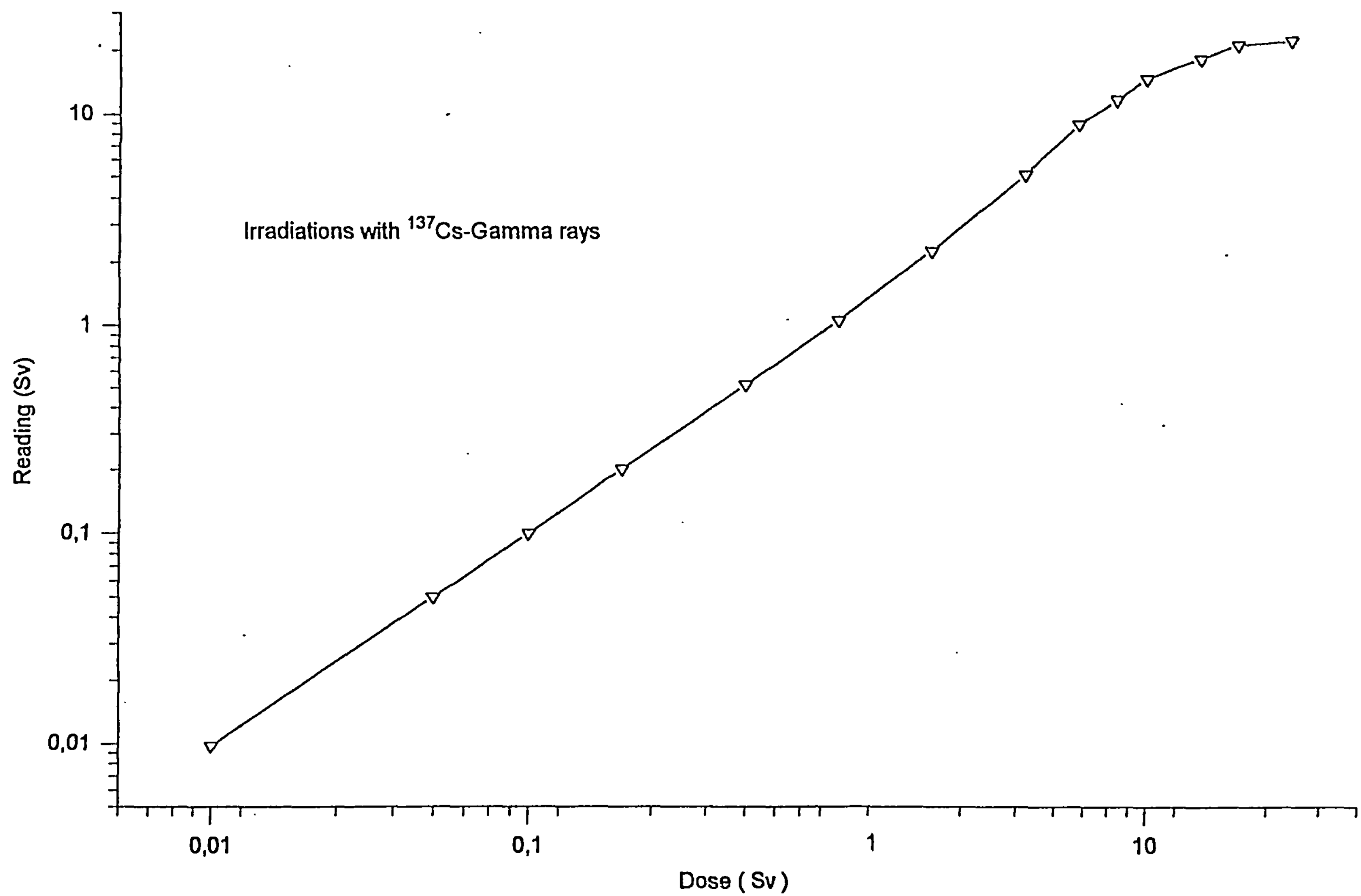

Fig. 6: Linearity in the High Dose Range

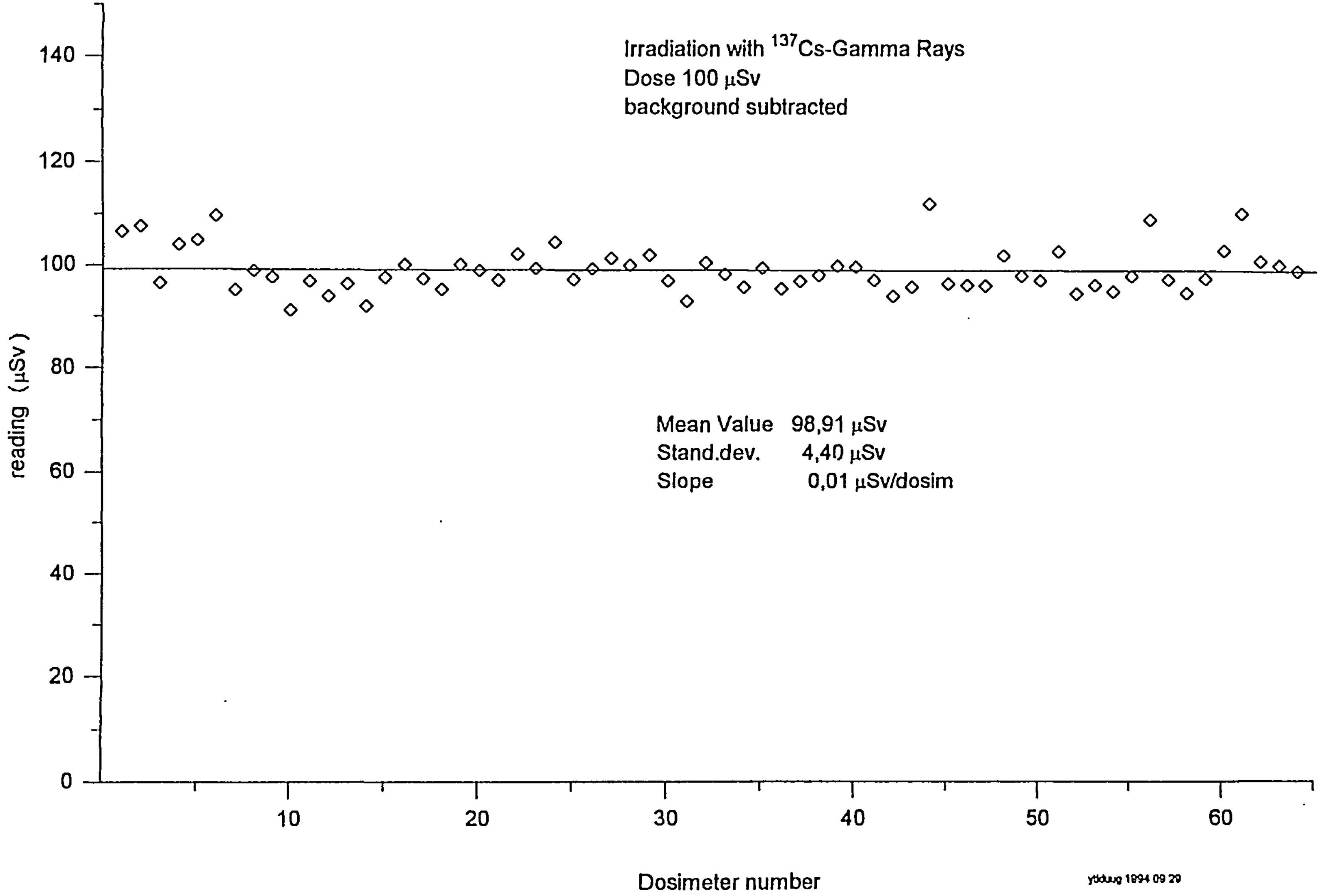

Fig. 7: Reproducibility of Dose Reading at 0,1 mSv for 70 Dosimeter Cards

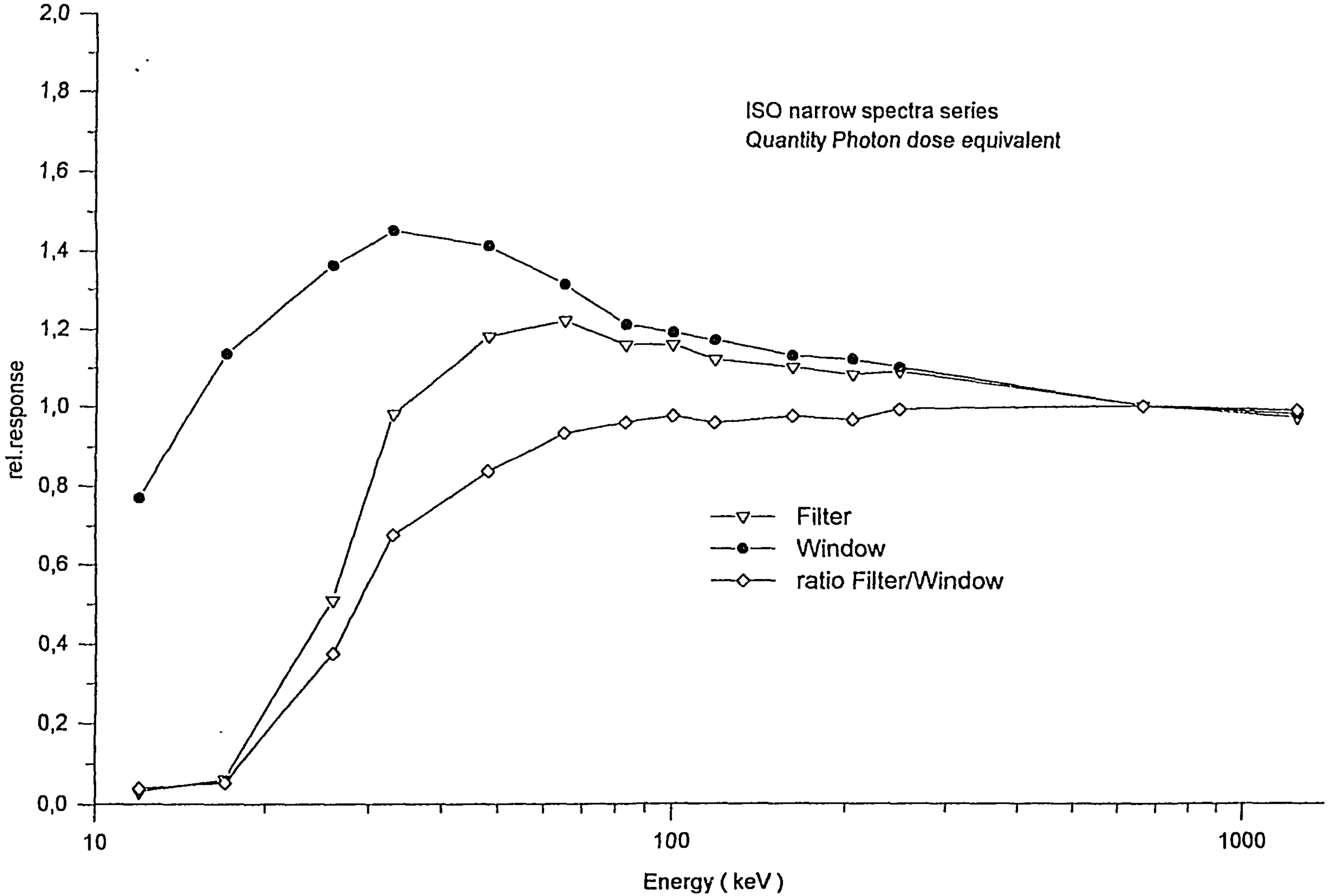

Fig.8: Energy Response of filtered and unfiltered TL element and ratio

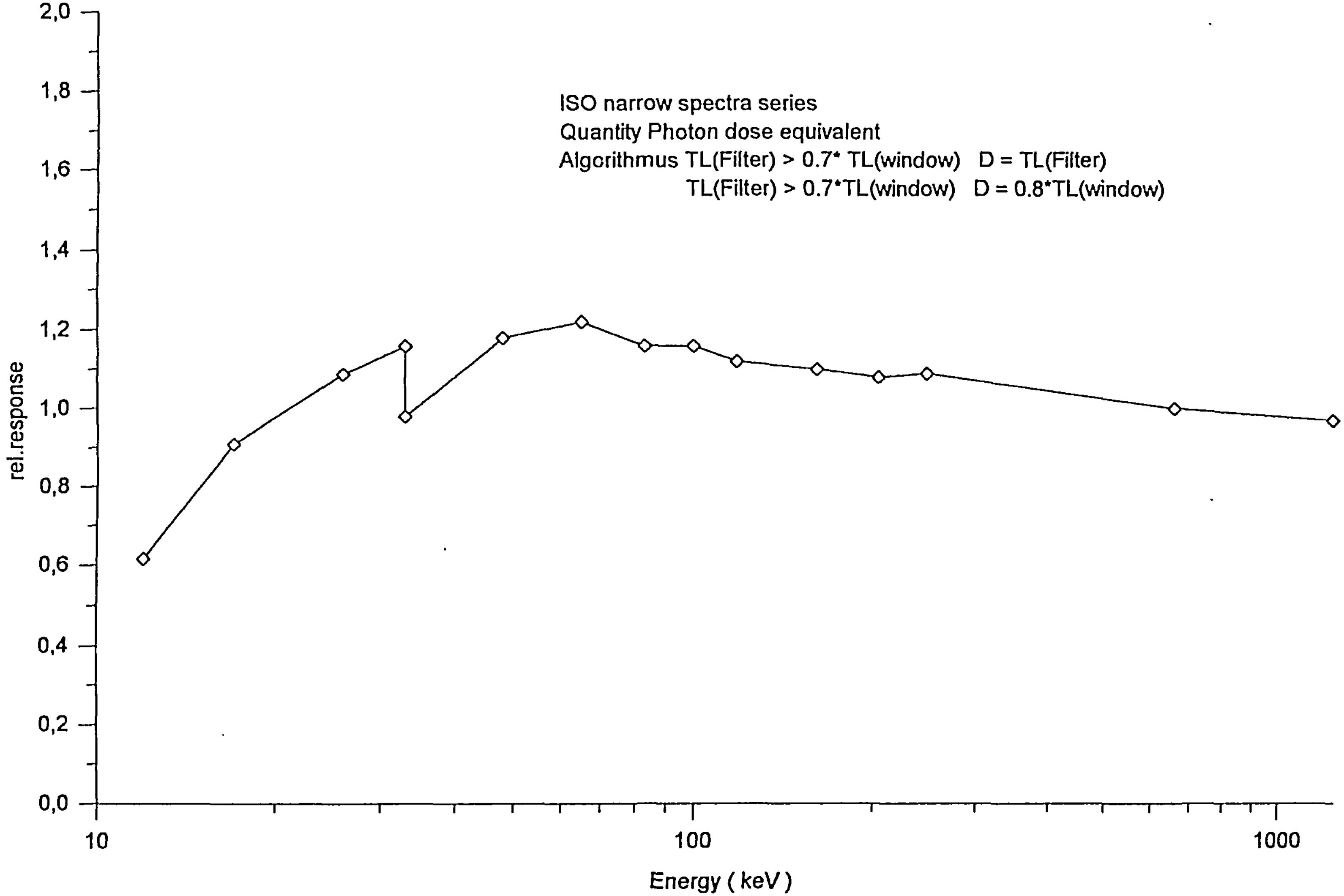

Fig. 9: Energy Response of dosimeter with readout algorithm applied

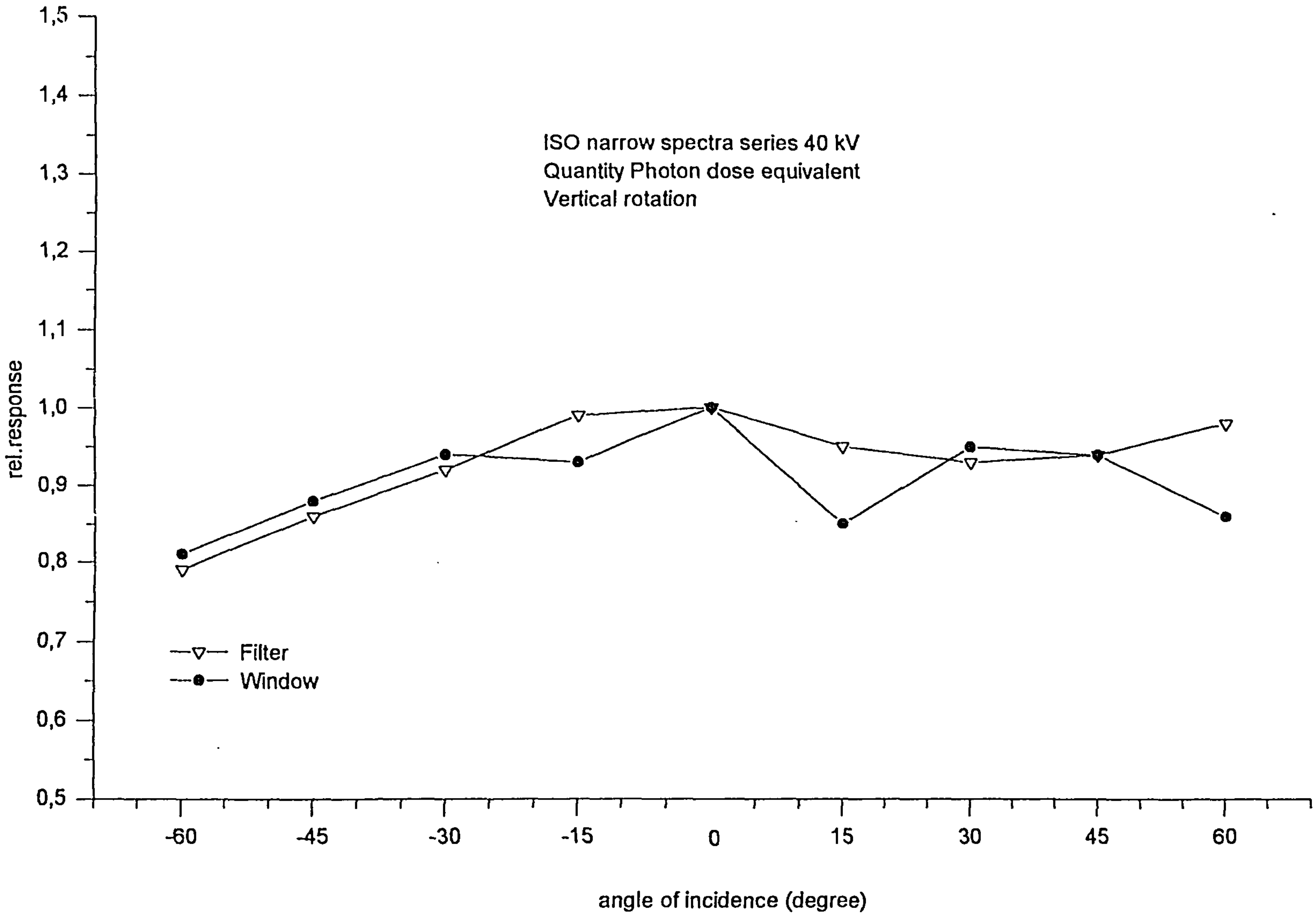

Fig. 10: Directional Response at 33 keV - Vertical Rotation

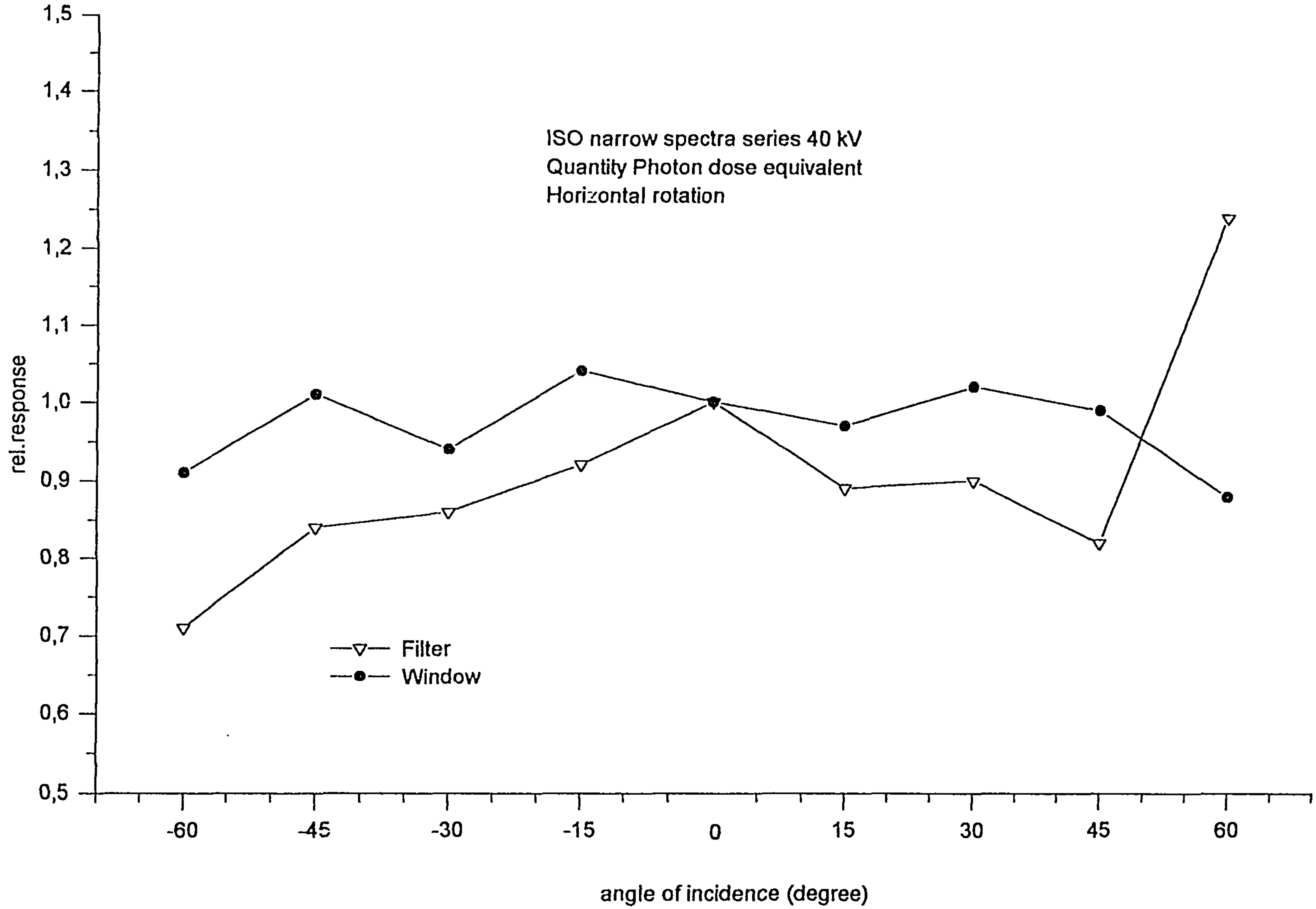

Fig. 11: Directional Response at 33 keV - Horizontal Rotation

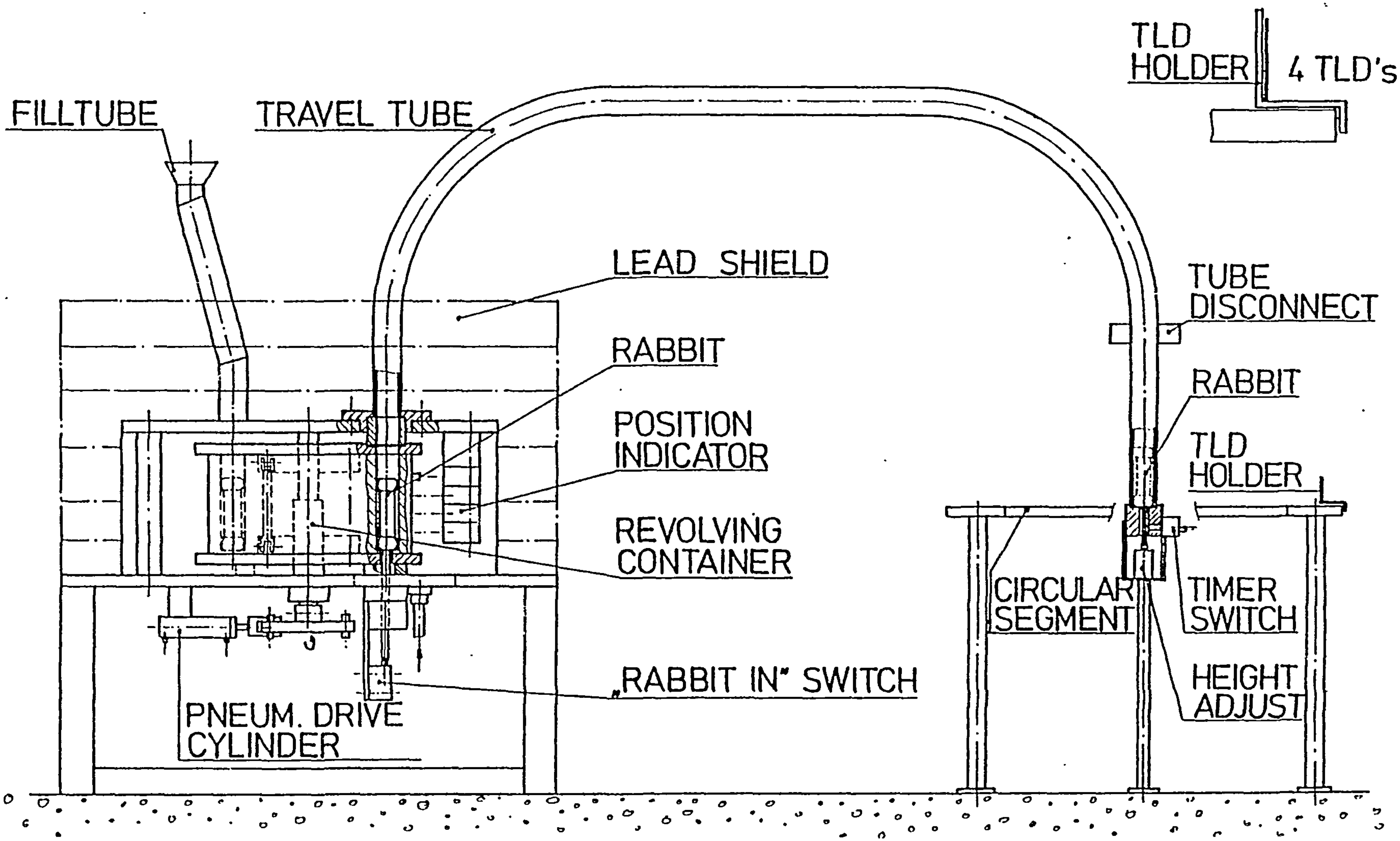

Fig. 12: Schematic View of Circular Exposure System

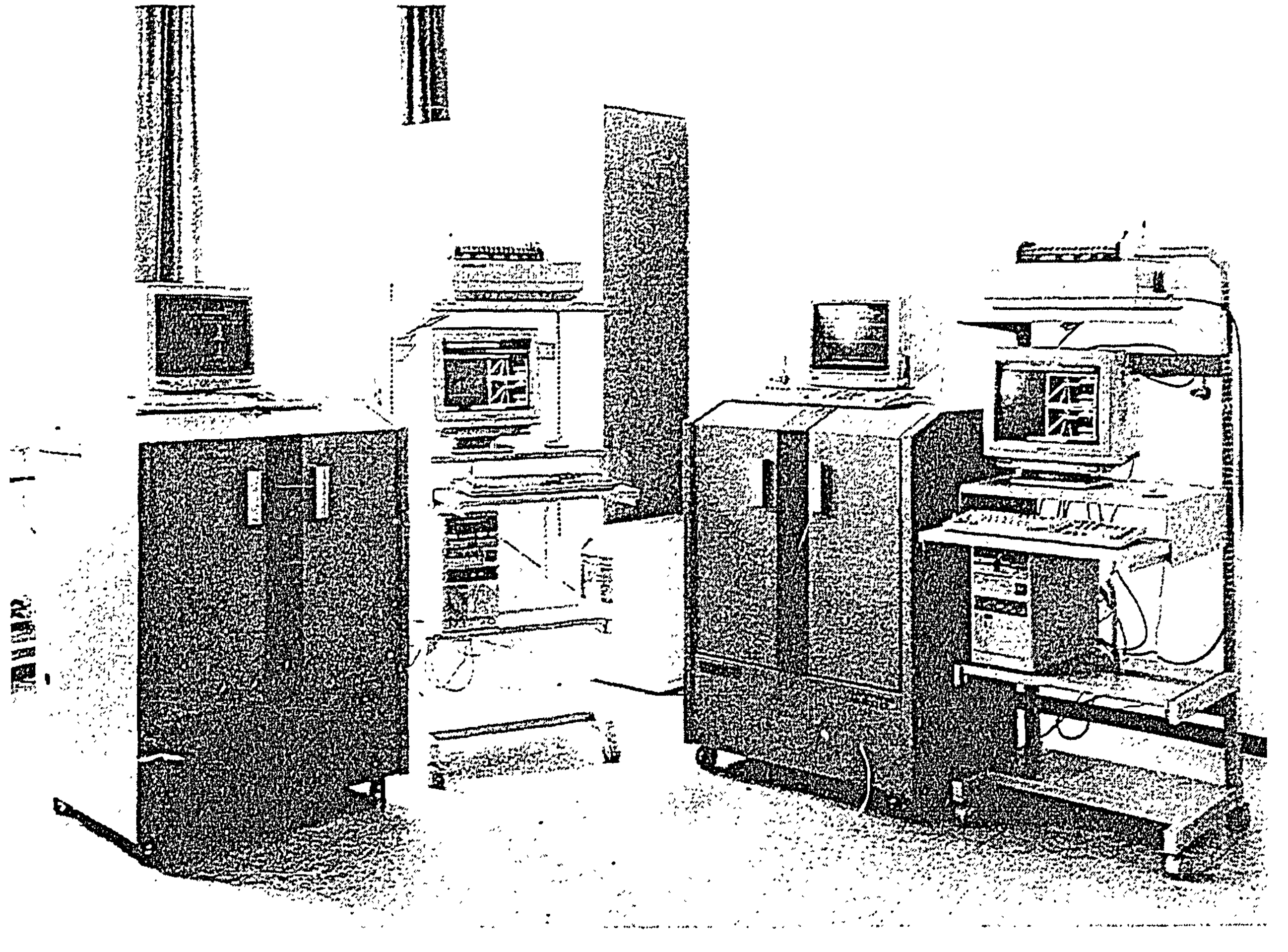

Fig.13: The Two HARSHAW 8800 Automated Reader Systems

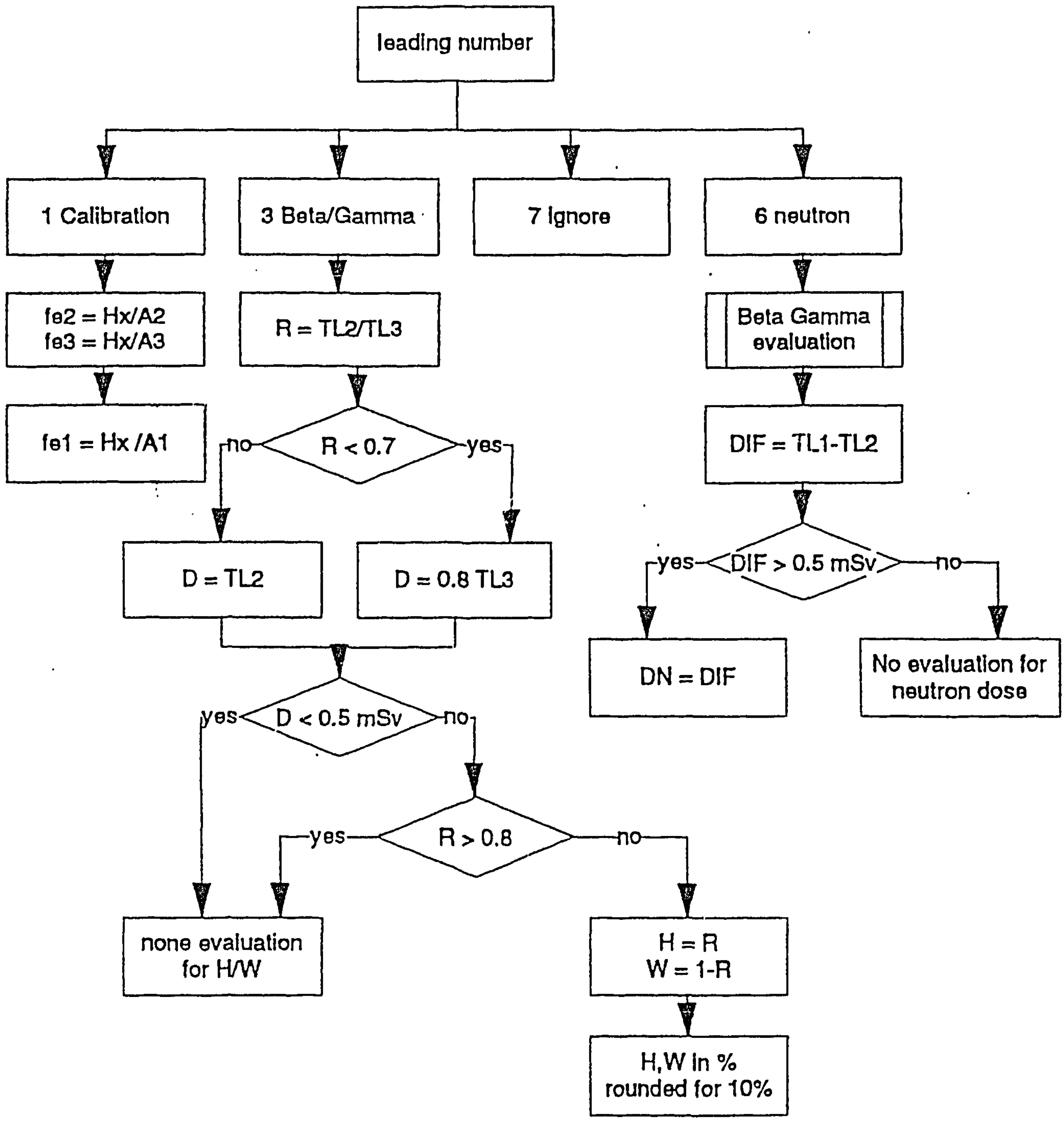

Fig.14: Flow Chart of Dose Calculation Algorithm

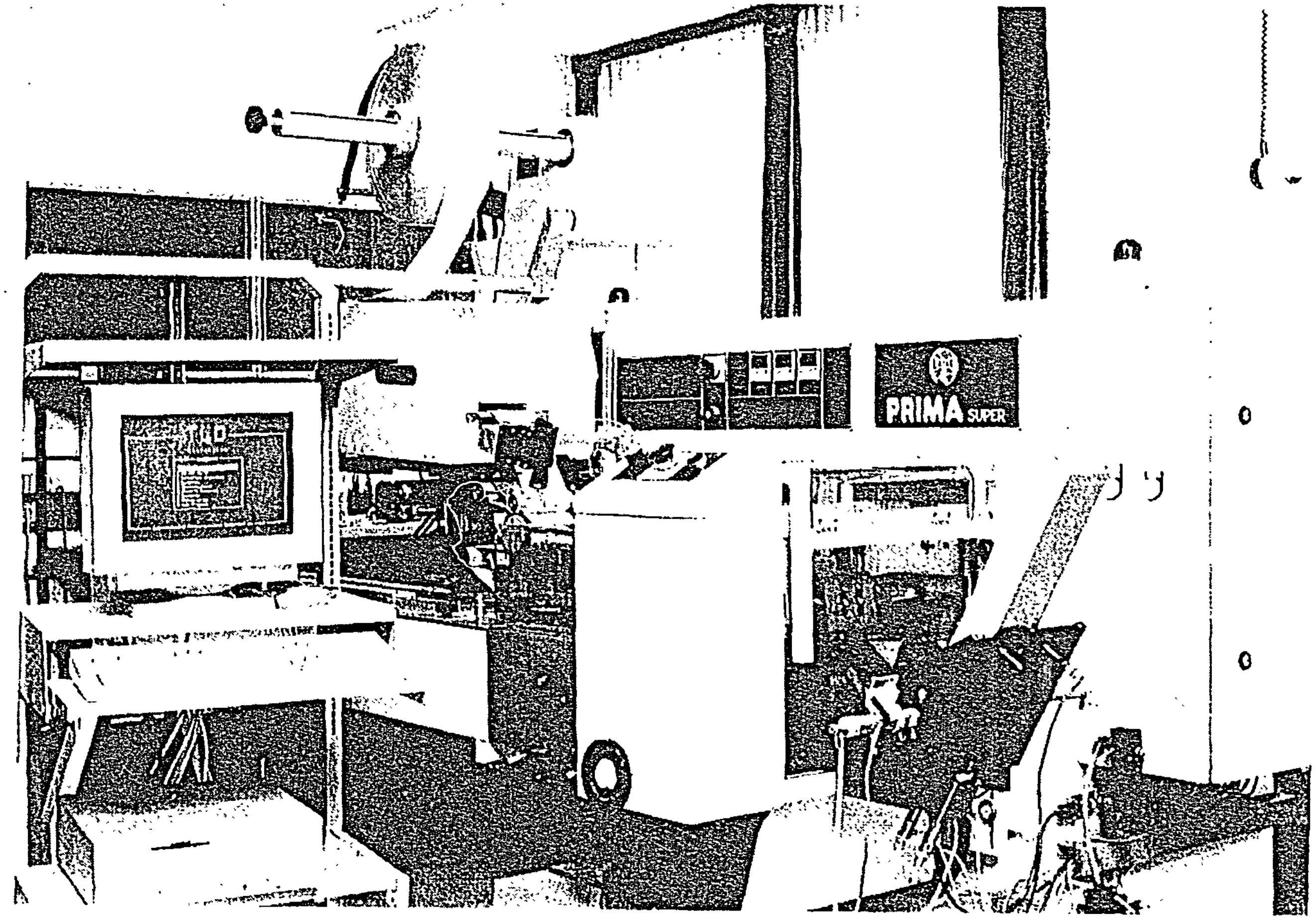

Fig.15: Automated Dosimeter Card Wrapping Machine with Control PC

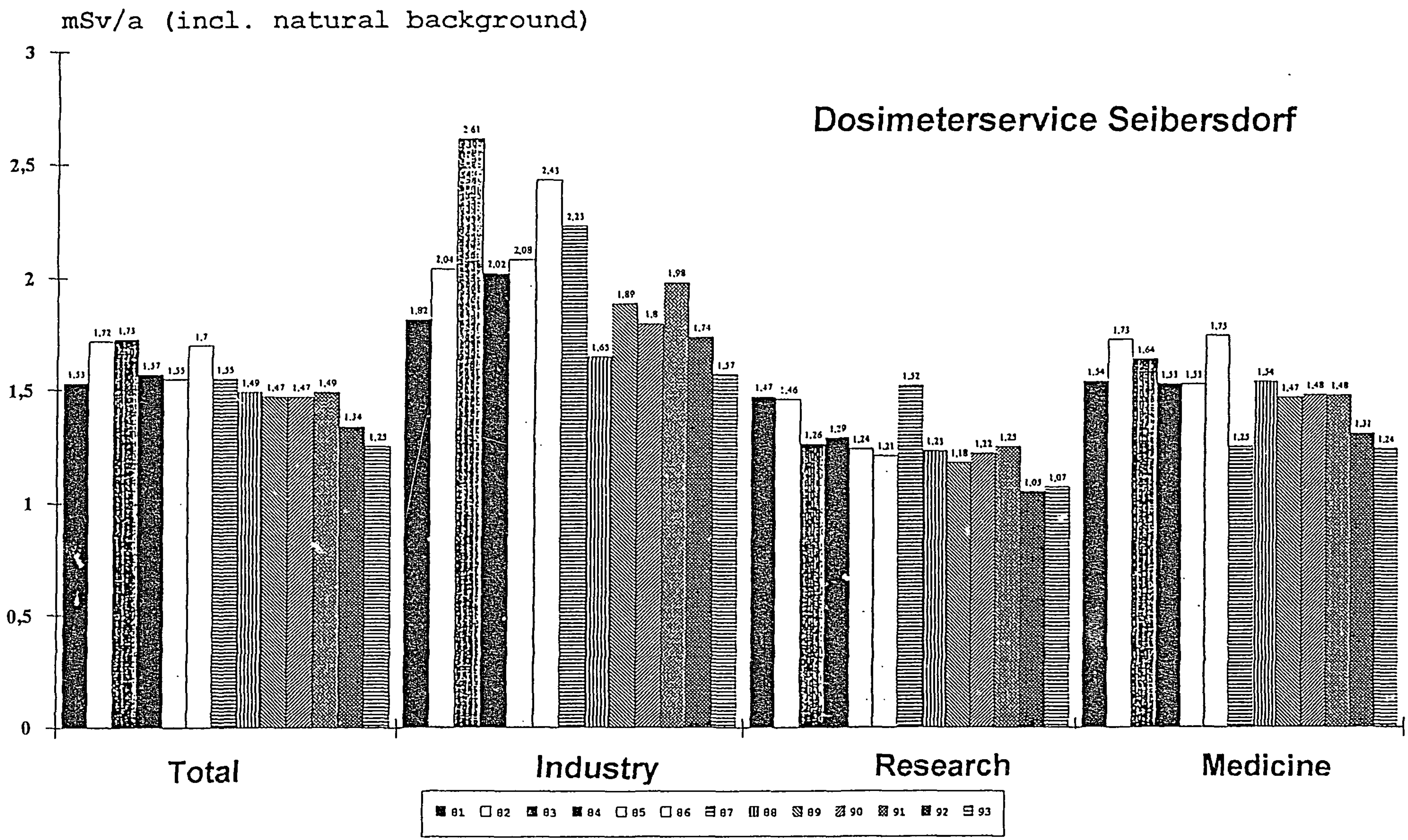

Fig.16: Statistical Evaluation of Central Dose Registry - Annual Average Doses 1981 - 1993

OEFZS-Berichte
ISSN 0253-5270
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