최종보고서

'99년 원자력연구개발 성과이전사업 신제품 개발지원사업

고에너지 선형가속기의 정도관리를 위한 선량측정시스템의 상품화

Development of Dosimetric System for quality Assurance of High-Energy Linear Accelerator

연구기관
(주)코디소프트 부설 정보 기술연구소

과 학 기 술 부

제 출 문

과 학 기 술 부 장 관 귀하

본 보고서를 “ ‘99 원자력연구개발 성과이전사업 신제품개발지원사업에 관한 연구” 과제 (세부과제 “ 「고에너지 선형가속기의 정도관리를 위한 선량측정 시스템의 상품화 」과제에 관한 연구”)의 최종보고서로 제출합니다.

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요 약 문

Ⅰ. 제 목

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- 산업/보건용 선량측정시스템의 상품화

S U M M A R Y
(영 문 요 약 문)

The dosimetirc system for daily and monthly quality assurance (QA) for Megavoltage Medical Linear accelerators has been devoloped. It consists of an ionization chamber and an electrometer. The ionization chamber is implemented by utilizing local-manufactured acrylic plate and home-made parallel-plate chambers. It is mounted onto the chamber assembly so that it can be inserted into the blocking tray holder of the linear accelerator. Therefore, it can eliminate the time-consuming setup procedure during daily and monthly QA, also more relaibale data can be achieved. High-voltage for the ionization chamber is provided by a 6V rechargeable battery, therefore it is possible to connect it to the electrometer via standard bi-axial cable. The electrometer employs the advaced technology of the analog-to-digital converters (ADC) and low-noise amplifier. The electrometer has RS-232 interface through which all measurements data are input to computer. The computer control the electrometer through RS232 port to get data from the ionization chamber. The data are saved into the computer, so later analyze the data as a part of Quality Assurance proceudre. This dosimetric system can be called "computerized dosimetric system"

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③ ionization chamber의 parallel-plate type의 전기/기구/방사선 특성

④ chamber assemblydml 기계적 구조: 선형가속기의 blocking tray에 장착

⑤ high-voltage generator 구성 (3 종류)

⑥ phantom material의 선정/chamber assembly 설계/제작

⑦ lab/engineering prototype의 설계/조립/제작/testing/보완

나. 방사선 측정기의 제작

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② 외국제 상용 장비의 자료수집

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㉯ System B 구성 (ion chamber + RF cable + digital electrometer)

㉰ System C 구성 (ion chamber + electrometer + RS232 + PC)

라. 선량계 system의 측정 protocol 개발

① X-ray beam의 측정 protocol

② Electron beam의 측정 protocol

마. 임상적용

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② SSD=67.5cm Setup의 측정 protocol의 결과

③ Air-ventilated type과 Air-tight type ionization chamber의 비교

④ Analog와 digital type의 electrometer 구성 (2, 8 channel)

⑤ PC용 GUI의 적정성 검토

바. 보완

① 기구적 측면의 개선

㉮ 0.5mm 이하의 기계적 재현성 유지

㉯ SSD=100/150cm 및 SSD=67.5cm 겸용의 setup이 가능한 구조

② 전기적 측정의 개선

㉮ stability 개선 (<0.2%)

㉯ zero-drift 개선 (<20fA)

㉰ leakage current 개선 (<20fA)

㉱ 광대역 증폭기

㉲ 저잡음 증폭기

③ computerized dosimetric system의 보완/개선

㉮ RS232 Communication Protocol

㉯ User Interface

㉰ QA용 Database구축

㉱ Statistics Tool 및 Display Function

사. 상품화를 위한 pilot type의 system 구성

① hand carry가 용이한 일체형 inonization chamber assembly

② 2/8 channel electrometer의 구현

③ Visual c++의 computer language를 이용한 computer interface

2절 연구개발의 필요성

1. 암환자의 증가

2. 암환자의 방사선치료의 증가

(가) 국내 매년 20,000명 암환자의 방사선 치료
(나) 미국의 경우, 3000개의 cancer center
(각각의 cancer center는 평균 3대 선형가속기 보유)
(다) 방사선치료기의 정도관리의 필요성 증가
① 국내에서는 1999년 8월 모 병원에서 방사선 과대 피폭으로 20여명의 환자발생 (KBS 8월 7일 9시 뉴스 보도)
② 국내에서도 원자력 안전청 등에서 선형가속기의 정도관리를 법제화 움직임
③ 1998년도 미국에서 근접치료기의 오작동으로 환자 사망
④ 미국 등에서는 지난 30년 동안 정도관리를 법적으로 제한
(라) 방사선치료기기의 증가
① 2002년에는 국내에만 85개의 치료방사선 center 예정
② 1999년 중국 내에만 1500개의 치료방사선 center 추정
③ 고가의 dosimetric system (20,000 - 40,000US$)
④ 국내 모대학에서의 치료방사선 사고

3. 선형가속기의 정도관리용 Dosimetric System (의료용 방사선 계측 system)

(가) 정도관리가 필요한 방사선치료기기
① 4 - 30MV의 의료용 선형가속기
② 4 - 30MV의 의료용 싸이클로트론
③ 의료용 neutron 발생장치
④ 고 선량률의 High-dose rate (HDR) unit
⑤ 자 선량률의 근접 치료기 (Brachytherapy unit)

(나) 1대의 선형가속기 일일 정도관리 (daily QA) 시 필요한 측정기기
① Farmer Chamber (100% 도입: 3,000US$)
② Tri-axial Cable & Connector (100% 도입: 2,000US$)
③ Electrometer (100% 도입: 20,000-40,000US$)

(다) 월별/년 정도관리 시 필요한 측정기기
① Water Phantom (100% 도입: 6,000 - 12,000US$)

② Water Scanner (100% 도입: 50,000 - 100,000US$)
③ Film Scanner (100% 도입: 10,000 - 40,000US$)
④ Flatness/Symmetry 측정기기 (100% 도입: 5,000 - 10,000US$)
⑤ Array detector (100% 도입: 5,000 - 10,000US$)
⑥ diode detector (100% 도입: 2,000 - 3000 US$)

4. 병원의 Radiation Monitoring System

(가) 방사선 치료실로 부터의 외부 방사선 측정용 (100% 도입)
① GM Counter (2,000US$)
② Survey Meter (2,000US$)
③ 저 에너지 neutron detector (60,000US$)
④ 방사선 치료실 주변의 Radiation Monitoring System (2,000US$)
⑤ 방사선원 저장실의 Radiation Monitoring System (3,000US$)

(나) 병실의 근접치료 환자의 Radiation Monitoring System (100% 도입)
(다) 진단방사선과 및 핵의학과의 Radiation Monitoring System (100% 도입)

3절 연구개발의 범위

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   (가) 일일정도관리를 위한 protocol 개발
   (나) 월별정도관리를 위한 protocol 개발

2. 방사선 치료용 고에너지 선형가속기의 정도관리를 위한 Dosimetric System의 개발
   (가) Ionization Chamber 개발
   (나) Electrometer의 개발
   (다) Computerized Dosimetric System
   (라) 측정 protocol 개발

3. 임상실험 (Varian Linear Accelerator 이용)
   (가) X-ray beam test (4-10MV X-ray 측정)
   (나) Electron beam test (6 - 20MeV electron 측정)

4. 보완
   (가) engineering prototype의 제작을 위한 기계적/전기적 보완
   (나) 임상실험 적용시 user의 요구사항 추가

5. Pilot type의 Dosimetric System의 개발

(가) 2/8 electrometer의 설계/제작

(나) ionization chamber와 electrometerdml 일체형 설계/제작

(다) QA system의로서의 전기적 특성/방사선 특성 측정

6. 상품화

(가) 국내/외 학회지 논문 발표

(나) 국내 의학 전문 학회의 장비 demo

(다) 해외학회 장비 demo

제 2 장 국내·외 기술개발 현황

1 절 국내 현황

1 학계동향

가 의학물리학

(1) 원자력병원 (KISTEP의 연구 project)

㉮ 선형가속기의 정도관리를 위하여 diode와 electrometer를 이용한 정도관리 system의 lab prototype 개발 완료

㉯ 상용화에는 미흡

(2) 전북대학교 의공학과 김부길교수팀 (KISTEP의 연구 project)

㉮ multichannel의 electrometer 개발

㉯ 8bit ADC채택

㉰ lab prototype 개발완료

㉱ 상용화에는 미흡

(3) 서울대학교 치료방사선과 하성환 교수 연구팀 (G7의 연구 project)

㉮ multichannel (5, and 9) electrometer 개발완료

㉯ multichannel (5, and 9) electrometer 개발완료

㉰ upgrade 준비중

나 원자력공학

(1) 서울대학교 핵공학과 최희동 교수팀

Van der Graph를 이용한 Spectrosopic 연구를 위한 선량 측정개발

(2) 서울대학교 핵공학과 강창순 교수팀

health physics의 선량 측정개발

(3) 한양대학교 이재기 교수팀

health physics의 Radon gas등의 선량측정

(4) KAIST의 BMRC 연구팀

영상 획득을 위한 detector 개발

다 대학병원

(1) 서울대학교 치료방사선과 강위생 교수 연구팀 (KISTEP의 연구 project)

㉮ 선형가속기의 정도관리를 위한 water phantom의 제작

㉯ block diagram 정도의 개발 진척

㉰ 고 감도 electrometer는 도입 추진중

(2) 아산대학 치료방사선과 이병용 교수 연구팀

㉮ 연구 차원에서 diode 및 간단한 electrometer 구현 (석사 논문)

㉯ film scanner 개발중

(3) 단국대학교 치료방사선과 윤형근 교수 연구팀

㉮ 본 연구소에서 개발한 chamber assembly test 완료

㉯ 본 system 분석은 단국대학교 의학물리사 신교철에의해 실시

㉰ 본 system을 단국대학병원에서 3개월간 임상 실험 완료

2 업계동향

가 방사선 계측기 생산업체

(1) (주) LISTEM (구 동아 X-ray)

㉮ 진단 방사선의 energy (최대 140KVp)용 radiation detector 개발중

㉯ CT dectector 개발중

(2) (주) 한일 X-ray

㉮ health physics용 survey meter (GM counter, Proportional counter)

㉯ detector는 도입하고 electrical system 구성완료

나 치료방사선관련 수입업체 (offer 상)

(1) 전성물산 (국내 최대의 치료방사선 장비 offer상)

㉮ 미국의 CNMC, Keithley, NE사의 장비 offer

㉯ 방사선 계측기 system의 국산화 추진 계획은 없슴

(2) 기타 4개 업체가 offer 업무 추진하고 있으나 국산화 추진계획은 없슴

2 절 국외 현황

가 고에너지 방사선 측정장비

(1) 미국 Keithley, CNMC, NE Technology, Nuclear Associates, Victoreen, PTW, EG&G, Sun Nuclear Corporation (부록 참조)
   ㉮ Model 35614, 35616 장비 개발완료 (표준장비)
   ㉯ 20년간 주요시장 확보 (미국내 3,000개의 cancer center)
   ㉰ 고가의 고에너지용 방사선 치료기 (8,000 - 20,000US$)
(2) Varian, Siemens, Philips사 등의 선형가속기 제조 전문업체
   ㉮ 고에너지 영상획득을 위한 detector 개발
   ㉯ detector는 도입하고 electrical system 구성완료
(3) Semiconductor등을 이용한 영상 장치 (진단 방사선과 기기)
   ㉮ detector는 Kodak, Fuji사 등의 3-4곳에서만 제작
   ㉯ detector 도입 후 system 구성은 10여개 사 추진 중

나 저 에너지 방사선 측정장비 (진단방사선과, 핵의학과)

(1) CT, 진단 X-ray detector용
   ㉮ 저 에너지 (30-140KVp) large volume (0.2- 1liter) ionization chamber
   ㉯ high-sensitivity electrometer (0.02 pC resolution and 20-bit ADC)
(2) health physics용 survey meter
   ㉮ 저에너지/저선량율의 survey meter
   ㉯ 저에너지/저선량율의 neutron survey meter

제 3 장 연구개발수행 내용 및 결과

1 절 이론적 접근

가 문헌 검토/전문가 협의

(1) 문헌 검토

㉮ AAPM, Red/Green Journal, Rad. Physics and Biology 문헌 자료수집

㉯ 대한방사선 방어학회/한국의학물리학회 자료수집

㉰ 외국의 상용화 장비 manual 입수/분석 (부록 참조)

㉱ 분석용 저가의 sample 장비 구입 (부록 참조)

- Farmer chamber, diode deetctor, inverse eng
- inverse engineering을 위한 중고 Keithley electrometer

(2) 전문가 협의

㉮ 고려대학교 김창선 교수 연구팀

㉯ 카톨릭대학교 이형구 교수 연구팀

㉰ 단국대학교 윤형근/신교철 교수 연구팀

㉱ KFDA의 정승환 연구팀

㉲ 서울대학교 치료방사선과 방사선사 팀

나 상용의 장비 사양 확보/검토 (부록 참조)

(1) 장비 선정 (Keithley사의 electrometer)

(2) 장비의 주요 parts 확인 (IC, capacitor, ADC converter)

(3) 장비 제작을 위한 부품수배/대치

다 선형가속기의 일일 정도관리의 사양 확정

(1) 국내 주요 대학병원의 일일 정도관리 protocol 파악

서울대병원 치료방사선과, 인하대병원 치료방사선과,
단국대병원 치료방사선과, 충남대병원 치료방사선과,
성균관대병원 치료방사선과,

(2) 국내 주요 대학병원의 일일 정도관리를 위한 장비 현황 파악

서울대병원 치료방사선과, 인하대병원 치료방사선과,
단국대병원 치료방사선과, 충남대병원 치료방사선과,
고려대병원 치료방사선과,

(3) 국외 주요 대학병원의 일일 정도관리 protocol 파악
- ㉮ University of Florida (Gainesville, Florida, USA)
- ㉯ Robert Boissoneault Oncology Institute (Ocala, Florida, USA)
- ㉰ Halifax Medical Center (Daytona, Florida, USA)

(4) 국외 주요 대학병원의 일일 정도관리를 위한 장비 현황 파악
- ㉮ 대학병원: 김시용 교수, University of Florida (Florida, USA)
- ㉯ 병원: Mr. Kevin Kalbaugh과 Miss Linda Ewald (medical physicist)
  Robert Boissoneault Oncology Institute (Ocala, Florida, USA)

마 ionization chamber의 제작

(1) cylindrical chamber의 전기적/기계적/방사선 특성
- ㉮ Farmer Chamber
- ㉯ 0.125cc small chamber

(2) parallel plate chamber 제작을 위한 표준 chamber 연구
- ㉮ Marcus chamber
- ㉯ Holt Chamber

바 electrometer의 제작

(1) 고유 회로의 설계/제작/실험
- ㉮ low-noise circuit (OPA128, ACF2101 amplifier)
- ㉯ low drift의 capacitor 선정 (적층 ceramic capacitor)
- ㉰ low-noise amplifier 선정

(2) 다목적용 ADC 회로 개발
- ㉮ 최대 23 bit (effective resolution) ADC 회로 구현
- ㉯ chamber 장착형과 별도의 electrometer제작을 위한 다목적 회로 구현
- ㉰ 안정된 voltage 공급을 위한 2.5V reference voltage generator 구현

(3) RS232의 communication protocol 구현

㉮ computer interface를 위한 회로

㉯ paperless computerized dosimetric system의 설계/제작

㉰ internet-based system 구현을 위한 기반기술

(4) multi-channel로의 확장성

- 최대 64 channel의 핵심 기술

(5) 무선/Internet을 이용한 환경 방사선 monitering system 개발 가능

- RF (radio frequency)를 이용한 방사선 data의 전송
- remote 제어가 가능한 방사선 계측 system 개발

사 Cable의 연구

(1) 100% 도입의 triaxial cable/connector 연구 대치 (3,000원/connector)

(2) 100% 국내제작의 cable 대치 연구 (12,000원/30 meter)

(3) 30meter RS232 cable interface 연구

아 phantom material의 연구

(1) Ionization chamber 제작을 위한 도입 material 연구

- Solid Water™, White Water™, Polystyrene™, Bakelite™ (부록 참조)

(2) Ionization chamber 제작을 위한 도입 material 연구

- 국내제작의 acrylic phantom (4종) 검토
- 방사선 특성 연구

자 단계별 Dosimetric System 구성 (1/2차 prototype 개발 완료)

(1) System A

㉮ ionization chamber (250V 단일 battery 이용, air-ventilated type)

㉯ 도입 tri-axial cable 이용

㉰ electrometer (OPA 128을 이용한 Amplifier, 10 bit ADC 이용)

(2) System B

㉮ ionization chamber

- 9V battery 이용한 300 +/- 5V의 high voltage generator 구현
- air-tight type의 ionization chamber

㉯ cable 국산화

㉰ electrometer (OPA 128을 이용한 Amplifier, 10 bit ADC 이용)

(3) System C

㉮ ionization chamber

(6V rechargeable battery에 의한 170V high-voltage generator 이용

㉯ electrometer (23 bit ADC)

- Low-noise amplifier: ACF2101
- ADC: ADS1210
- RS232 communication interface

㉰ PC interface: Computerized Dosimetric System

㉱ Data Processing Tool

차. 실험/검증/보완

(1) dosimetric system의 실험 protocol 작성

(2) X-ray beam

㉮ Varian 선형가속기 (서울대: CL2100C, 4/100. 6/100, 단국대:1800C 4종)

㉯ X-ray Energy: 4 - 15MV

㉰ SSD setup: 65 - 100cm (option: 150cm)

㉱ Dose Range: 20 - 320 cGy (5 decades)

(3) Electron beam

㉮ Varian 선형가속기이용 (서울대 CL2100C, 단국대 CL1800C 2종)

㉯ Electron Energy: 6 - 20MeV

㉰ SSD setup: 100cm

㉱ Dose Range: 20 - 320 cGy

(4) 실험결과 확인/비교을 위한 외국제 장비 선정

㉮ water phantom (독일 Wellhopper 장비)

㉯ 0.6cc Farmer Chamber (부록 참조)

㉰ NE Dosimeter Type 2620 (부록 참조)

카 국내/외 논문 발표

(1) 대한 방사선 치료기술학회 (서울대학교 치료방사선과 서석진)

(2) 한국/일본 의학물리학회 (코디소프트 허순녕)

타 상품화 /보완 (방사선 특성에 관한 보완연구 요구됨)

(1) 상품화 (engineering prototype) 장비의 사양 (아래 표 참조)

(2) 한국의학물리학회 전시 (부록의 catalog의 사진 참조)

(3) Indonesia "Connectivity 2000" 전시 (부록의 catalog의 사진 참조)

(4) 장비 전시/demo후 user의 feedback 추가

- 고해상도 요구: 10bit ADC에서 20bit ADC로 수정
- LCD에의한 user interface
- multichannel electrometer의 구현 (8 channel)

No	사양	항목	사양	비고
1	ionization chamber	sensitive volume	1.0cc	
2		chamber type	parallel plate with air-tight	
3		electrode	Cu/Pb/Ag coating	
4		high voltage	317 +/- 1V (oscillator type)	
5		buildup plate	acrylic plate	
6		maximum field size	30cm*30cm	
7		weight	~4Kg (including buildup plate)	
8	electrometer	channel number	1 - 8 channels	
9		cable	with RG-59 and BNC connector	
10		ranges	3 (200pc - 20nC)	
11		ADC	16 bit (20 bit option)	
12		computer interface	LCD or RS-232 interface	
13		main power	free voltage (85 - 220V_{ac})	
14		weight	< 2.5Kg	

2 절 실험적 접근

가. 선형가속기의 일일 정도관리의 현황파악

(1) 서울지역과 일부 대형대학병원의 경우 (약 10개소)

㉮ 일일 정도관리의 항목

① X-ray/Electron의 Output check
(stability, repeatability, reproducibility)

② X-ray/Electron의 Energy check

③ Safety 조사
(emergency, audio/visual-laser check/SSD meter의 일치성)

㉯ 월별 정도관리의 항목

① X-ray/Electron의 wedge field와 open field의 Output/Energy 측정

② Radiation Measurements: profile, TMR 또는 PDD

③ Wedge Factor, Tray Factor, Field Size Dependency (FSD),

④ Dose Rate Effect, Linearity, Stability (Repeatability),

⑤ Elongated Field Effect, Radiation/Light Field Matching,

⑥ Mechanical Parameters
(Gantry/Table/Collimator rotational accuracy
Safety, Interlock, Audio/Visual Warning, Key Borad, Pendent
Emergency Switch)

㉰ 연별 정도관리의 항목

① 월별 정도관리의 항목포함

② Beam Data 측정
Profile, PDD, FSD, Output Factor,
one Factor, Wedge Factor, SSD Factor, Virtual SSD,
Tray Factor

③ Dosimetric System의 정도관리
(Stability, Linearity, Timer Error, Elongated Field Effect,
Zero-drift current, Leakage Current, Cable Damage, 등등)

(2) 기타 소형 대학병원의 경우 (45개소: 국내 80% 이상의 병원)

㉮ 일일 정도관리의 항목

① 월별/년월 정도관리로 대치 또는 일일 정도관리의 protocol이 없슴

② 일일 정도관리의 장비가 고가이므로 구매불가

③ 월별 정도관리의 항목

- 대형대학병원도 protocol의 일부분만 시행
- 월별 정도관리의 장비가 고가
- 30%의 대학병원에 full-time의 physiciust가 없슴

④ 연별 정도관리의 항목

"월별 정도관리의 항목"의 내용과 같음

㉯ 선형가속기의 일일/월별/년월 정도관리용 방사선 계측기의 현황

대부분의 병원은 10여년전에 이들 장비를 구매하여 대부분 노후하였으며, IMF, 의약분업에 따른 예산상의 문제로 구매가 불가하고 구매시 다음의 예산이 예상된다.

① 서울지역과 일부 대형대학병원의 경우 (국내 55개의 병원중 약 10개소)

- water scanner (200,000 US$)
- water phantom (20,000US$)
- Farmer Chamber (4,000 US$)
- Digital Electrometer (8,000 - 20,000 US$)

② 기타 소형 대학병원의 경우 (45개소)

- water scanner (200,000 US$)
- Farmer Chamber (4,000 US$)
- Digital Electrometer (8,000 - 20,000 US$)

㉰ 이러한 상황에서 개발하고자 하는 정도관리 system의 사양/조건

① 측정하고자하는 radiation type

- X-ray Beam : 4, 6, 10, 15, 20MV
- Electron Beam : 6, 8, 9, 12, 15, 20, 25MeV

② 측정하고자하는 Setup 및 조건

- SSD = 67.5cm과 100cm SSD Setup
- Dose Rate: 40 - 400 cGy/min
- Linearity : 20 - 320 cGy
- Wedge Factor: 15, 30, 45, 60, Dynamic Wedge

item	setting	측정 조건	parameter	비고
stability	100MU (또는 200MU) 240cGy/min Dose rate 10cm*10cm Field Size SSD = 67.5 또는 100cm	20번 (또는 10회)	average standard deviation	stability index (in %) =(standard deviation)/avg
linearity	20, 40, 80, 160, 320MU 240cGy/min Dose rate 10cm*10cm Field Size SSD = 67.5 또는 100cm	각3회	5 point data를 이용한 LMS fit	측정 data와 LMS fit 한 data간의 percentage 차이
Dose Rate Effect	100MU (또는 200MU) 80 - 400 cGy/min (80,160,240,320,400cGY/min) 10cm*10cm Field Size SSD = 67.5 또는 100cm	각3회	5 point data의 비교	5 point data의 average와 최대/소 값의 percentage 값
Leakage Current	100MU (또는 200MU) 240cGy/min Dose rate 10cm*10cm Field Size SSD = 67.5 또는 100cm	각3회	방사선 조사후 1min (또는 3 min) 경과후 reading 값	방사선조사후 reading과 1 min (또는 3min) 경과후의 reading의 percentage 값
Zero-drift current	Electrometer를 reset한후의 reading	각3회	reset후 1min (또는 3min) 경과후 reading	reading/average in stability (% value)
Timer Error	200MU 조사한후의 reading과 50MU를 계속해서 4번 조사한 후의 reading	각3회	50MU를 계속해서 4번조사하는 경우에는 조사시의 시간 차이는 최소화한다 (15-20초)	2개의 reading의 percentage 차이

표 3. 2. 1 측정항목의 protocol

③ 개발되어야할 system의 일반사양

- 가격: 300만원대
- Setup 시간: 1 - 2분
- Warmup time: 15분이내
- GUI: 사용하기가 쉬운 user interface
- 부품의 선정: 일반 부품으로 고장시 국내에서 부품 수배가 용이
- 확장성: 병원용, 환경 방사선 측정용의로 확장이 용이한 구조

④ 본과제에서 개발하고자하는 system의 예상 사양

- SSD=67.5cm setup이 용이한 선형가속기 blocking tray장착형
- SSD=100cm setup도 가능
- X-ray/Electron Beam의 output factor, stability 측정 가능
- Setup time: "1분이하" (기존의 장비 이용시 ~1시간 소요)
- Temperature/Pressure의 보상이 없는 air-tight 형태의 chamber
- 고가/damage가 용이한 triaxial cable 대치
- SSD=100cm setup이 가능
- X-ray/Electron Beam의 output factor, stability 측정 가능
- Setup time: 10분이하
- Temperature/Pressure의 보상이 없는 air-tight 형태의 chamber
- 고가의 water phantom 대치
- 측정 data의 전산화

㉱. 정도관리 system의 방사선 계측기 관련 사양

① 방사선 특성

- 방사선 측정 기준조건의 설정
- 측정항목의 protocol (표 3. 2. 1 참조)
- 측정항목의 protocol (기준 setting은 (가) 참조)

② 주요 전기적 특성

- ionization chamber

sensitive volume, leakage current, RF shielding: minimal
air-tight와 air-ventilated type, collection efficiency

pertubation factor, replacement factor: < 1.02
high-voltage

- electrometer
  leakage current, drift current, ADC resolution
  input impedance: >1GΩ, LCD display, 100/200Volts
  ADC의 dynamic range (-10 to +10V)
- dosimetric system
  charge range, precision, cable type, RS-232 Interface
  connector (BNC type), leakage current, zero drift current

③ 주요 일반적 특성

- ionization chamber assembly
  - ※ type: portable (built-in 구조) with handle
  - ※ size: 30cm*30cm*(10cm 이하)
  - ※ weight: < 4Kg
  - ※ backscattering material: >5cm
  - ※ buildup plate: 3cm, 5cm
  - ※ locking mechanism: wedge와 pin 구조 (기계적 정확도< 0.5mm)

- electrometer assembly
  - ※ housing material: Aluminum
  - ※ structure: modular structure
  - ※ power: free-voltage generator (110/220 AC Volts)
  - ※ display: 3 1/2 digit의 LCD (> 3 digits)
  - ※ computer interface: RS-232
  - ※ channel 수: 최대 64 channels (1,2, 8 channels)

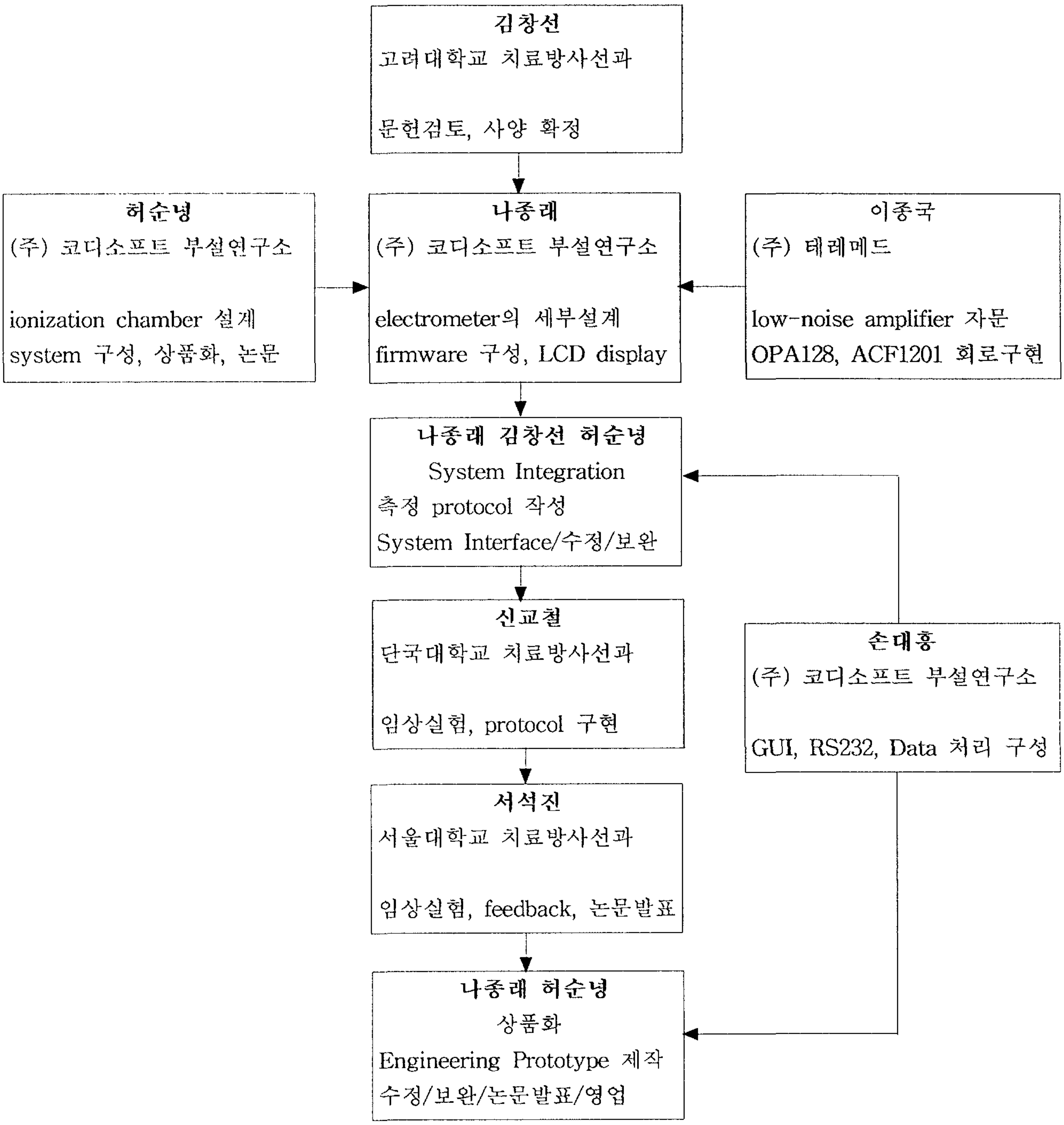
- Computer Interface (System C인 경우)
  - ※ Environments: Windows NT
  - ※ Programming Language: Visual C++ (version 6.0)
  - ※ Database: 기기/일자별 database 구축
  - ※ Statistics Tool 제공

※ "Paperless" dosimetric system 구현

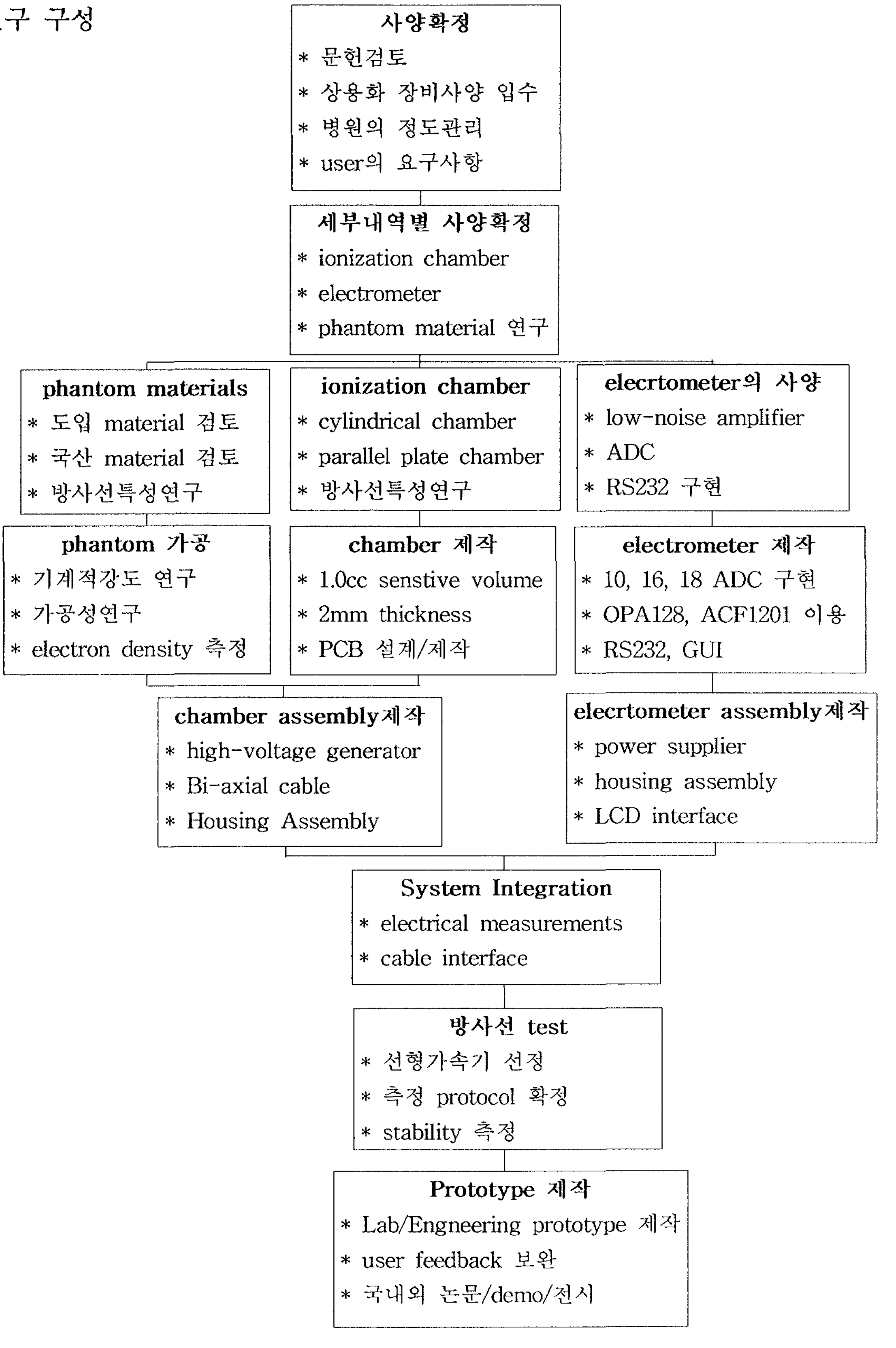
※ Internet-based data analysis tool (향후)

3 절 연구 팀구성 (연구수행 방법상 기술적인 상세자료 부족)

1 도해적 연구 팀구성

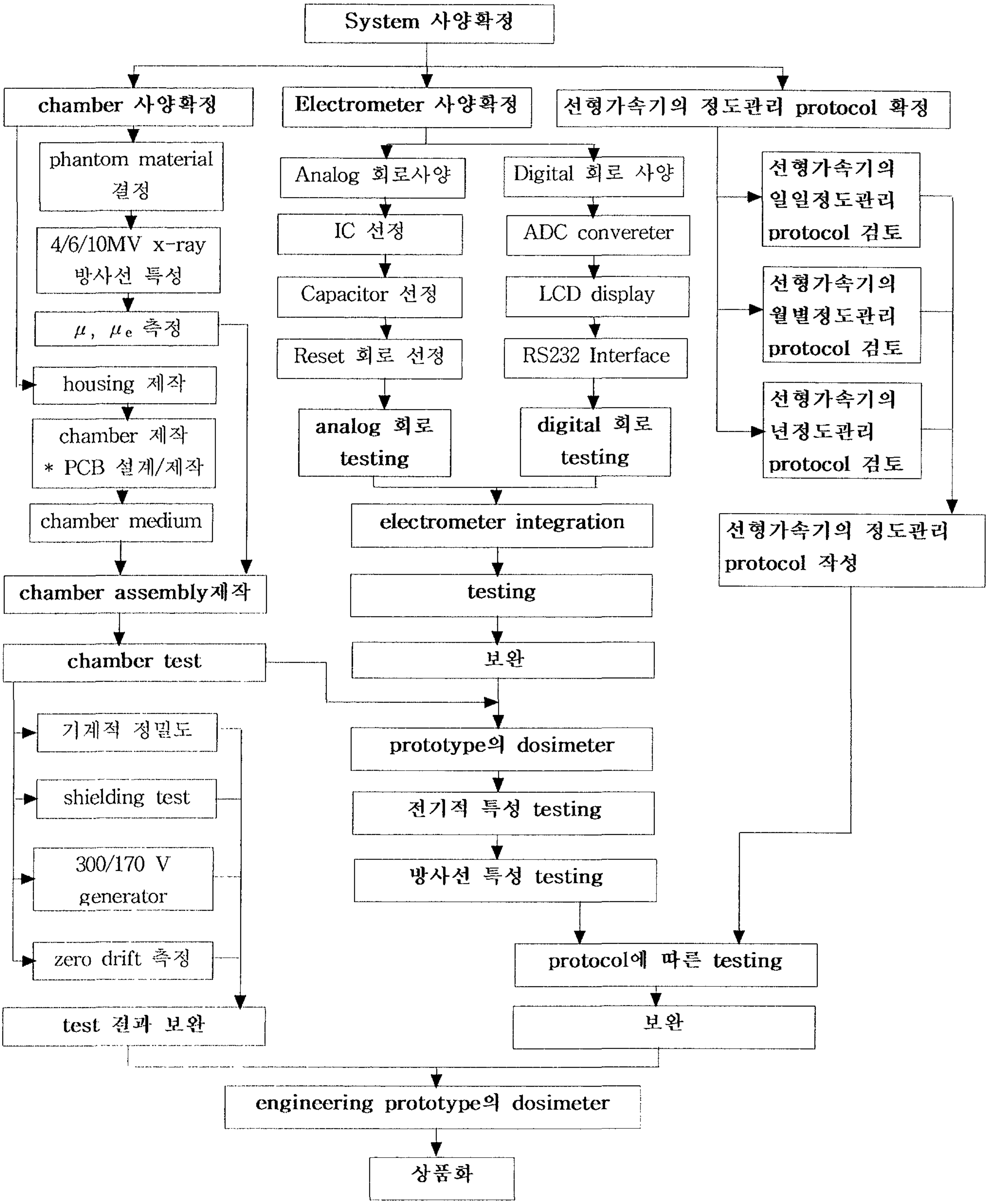


2 업무별 연구 구성



사양확정
* 문헌검토
* 상용화 장비사양 입수
* 병원의 정도관리
* user의 요구사항
세부내역별 사양확정
* ionization chamber
* electrometer
* phantom material 연구
phantom materials
* 도입 material 검토
* 국산 material 검토
* 방사선특성연구
ionization chamber
* cylindrical chamber
* parallel plate chamber
* 방사선특성연구
elecrtometer의 사양
* low-noise amplifier
* ADC
* RS232 구현
phantom 가공
* 기계적강도 연구
* 가공성연구
* electron density 측정
chamber 제작
* 1.0cc senstive volume
* 2mm thickness
* PCB 설계/제작
electrometer 제작
* 10, 16, 18 ADC 구현
* OPA128, ACF1201 이용
* RS232, GUI
chamber assembly제작
* high-voltage generator
* Bi-axial cable
* Housing Assembly
elecrtometer assembly제작
* power supplier
* housing assembly
* LCD interface
System Integration
* electrical measurements
* cable interface
방사선 test
* 선형가속기 선정
* 측정 protocol 확정
* stability 측정
Prototype 제작
* Lab/Engneering prototype 제작
* user feedback 보완
* 국내외 논문/demo/전시

3 세부 업무별 팀구성


System 사양확정
chamber 사양확정
Electrometer 사양확정
선형가속기의 정도관리 protocol 확정
phantom material 결정
4/6/10MV x-ray 방사선 특성
μ, μe 측정
housing 제작
chamber 제작 * PCB 설계/제작
chamber medium
chamber assembly제작
chamber test
기계적 정밀도
shielding test
300/170 V generator
zero drift 측정
test 결과 보완
Analog 회로사양
IC 선정
Capacitor 선정
Reset 회로 선정
analog 회로 testing
Digital 회로 사양
ADC convereter
LCD display
RS232 Interface
digital 회로 testing
electrometer integration
testing
보완
prototype의 dosimeter
전기적 특성 testing
방사선 특성 testing
선형가속기의 일일정도관리 protocol 검토
선형가속기의 월별정도관리 protocol 검토
선형가속기의 년정도관리 protocol 검토
선형가속기의 정도관리 protocol 작성
protocol에 따른 testing
보완
engineering prototype의 dosimeter
상품화

4절 연구 내용

가. 선형가속기의 일일/월별 정도관리 사양

1. 의료용 선형가속기의 일일/월별 정도관리 (AAPM 권고내용: FM Khan, Ph.D.)

(가) 일일 정도관리 (방사선관련만 포함)

(1) 측정 항목: X-ray의 output, energy 측정

(2) 측정 기기: Framer chamber, electrometer, water-equivalent phantom

(나) 월별 정도관리 (방사선관련만 포함)

(1) X-ray beam의 측정 항목: output, energy, Field Size Dependency (FSD), Wedge Factor, Tray Factor, Source-to-Surface (SSD) Factor, Dosimetric System (ionization chambver와 electrometer)

(2) 측정 기기: Farmer chamber, electrometer, water-equivalent phantom, Water Phantom/Scanner

2. 국내대학 병원의 일일/월별 정도관리 (방사선관련만 포함)

(가) 일일 정도관리 (국내 병원의 10% 정도만 시행)

(1) 측정 항목: X-ray의 output

(2) 측정 기기: Framer chamber, electrometer, water-equivalent phantom

(나) 월별 정도관리 (국내 병원의 30% 정도만 권고사항의 80%만 시행)

(1) X-ray beam의 측정: output, energy, Field Size Dependency (FSD) Wedge Factor, Tray Factor, Source-to-Surface (SSD) Factor

(2) Electron beam beam의 측정 항목: output, R_{50}, R_{20}, Cone Factor, Virtual Source-to-Surface (VSSD) Factor

(3) 측정 기기: Framer chamber, electrometer, water-equivalent phantom, Water Phantom

나. Dosimetric System의 사양

1. Calibration 장비의 system의 일반 요구사양

(가) Ionization Chamber의 setup (그림   참조)
- 0.6cc Farmer with Buildup Cap (외국제 경우 2,000 US$)
- PMMA, Solid Water phantom (외국제 경우 8,000-12,000 US$)

(나) Electrometer (Keithley 35614, NE type 2620)
- 3 1/2 또는 4 1/2 Display
- Resolution: < 0.1pC (6,10MV X-ray와 100cGy 기준대비: < 0.2%)
- high-voltage generator: 170/330 +/- 5 Volts
- computer interface: RS-232 (serial communication)
- linearity, precision, accuracy, stability: < 0.2%

2. 일반 정도관리 장비의 system의 구성

(가) Ionization Chamber의 setup
- 0.6cc Farmer 또는 diode detector 기준
- PMMA, water-equivalent phantom 기준
- water scanner 또는 small water phantom
- tri-/bi-axial cable (RG-38)

(나) Electrometer 또는 Digital Electrometer
- 3-Digit Display
- Accuracy/Precison: < 1%
- Stability: < 1%
- linearity: < 1%

다. ionization chamber의 구성

1. 일반적인 ionization chamber의 사양

(가) 전기적 사양 (표 3. 2. 2 참조)

(나) 방사선 특성 (표 3. 2. 3 참조)

(다) 용도별 특성 (표 3. 2. 4 참조)

(라) 정도관리용 Semi-conductor detector의 문제점

(1) radiation damage: 10,000Gy 피폭시 10% sensitivity 저하
(2) 고가의 diode detector: 1,500 US$ (set당 5~8개 필요)
(3) 50uV 이하의 offset voltage를 갖는 electrometer의 구현
① 상용의 정도관리용 digital electrometer: 2,000 US$
② muti-channel로의 확장시 electrometer: 8,000 US$
③ dark current에 따른 저 해상도 (+/- 1 %의 accuracy)

No	item	specification	condition	remark
1	radiation type	X-ray/Electron	X-ray: 10*10 - 30*30cm^2 Electron: 10*10 - 30*30 cones	
2	dose rate	80 - 400cGy/min	240cGy/min: 기준	
3	dose	20 - 320 cGy	SSD=100cm 기준	
4	SSD	X-ray: 60 - 120cm Electron: 100 - 120cm		
5	Charge Response	20nC/Gy		
6	Leakage Current	< 20fA		
7	Ion Collection Time	< 0.3msec		high-voltage 와 연동
8	connector	BNC, TNC	BNC: 본연구위 electrometer TNC: 기존의 electrometer	

표 3. 2. 2. Ionization chamber의 방사선 특성

(주 1) SSD: source-to-surface distance
(주 2) cGy: 1 cGy = 1 Rad

No	item	specification		condition	remark
		외국제	본연구목표		
1	구조	cylindrical, parallel-plate	parallel-plate		제작이 용이
2	재질	graphite, PMMA	acrylic	국산 acrylic plate	
3	gas	air	air		향후 liquiㅇ
4	전극	graphite, 전도성 plastic	Cu/Gold (100um 두께)	Printed Circuit Board (PCB) 이용	
5	Stem	Aluminum	Cu strip	stem effect: <0.5%	측정치
6	High-voltage	300-500V	170, 300V	(collection eff. > 0.995)	변경가능
7	Air type	ventilate	ventilate, tight	No TP compensation	
8	sensitive volume	0.01 - 0.6cc	0.6cc	electrometer와 연동	변경가능
9	cable	tri-axial cable	bi-axial cable	국산 cable	
10	connector	tri-axial connector	BNC connector	국산 connector	

표 3. 2. 3. Ionization chamber의 전기적 특성

No	사양	용도별			Remark
		진단 X-ray 용	Survey meter용	치료방사선 용도	
1	X-ray Energy	< 140KVp	수 KVp - 수MV	1.25 - 30MV	
2	Radiation Unit	Exposure	Exposure	Dose	
3	Radiation Type	X, E	X, E, n, α	X, E, n	
4	Accuracy	+/- 10%	+/- 50%	< 0.5%	
5	Sensitive Volume	1cc - 30cc	200cc - 1000cc	0.1 - 0.6cc	
6	material	graphite, PMMA	graphite, thin Cu	PMMA, acrylic polystyrene	

표 3. 2. 4. 용도별 사양

2. 선형가속기의 정도관리를 위한 ionization chamber의 사양

(가) 상용의 parallel plate chamber와의 사양과 목표사양
(1) 전기적 특성 (표 3. 2. 5 참조)
(2) 방사선/재료적 비교사항 (표 3. 2. 6 참조)

(나) 본연구의 chamber의 구조 (단면도)
(1) 단면도 (그림 3. 2. 1 참조)
(2) signal electrode (그림 3. 2. 2 참조)
(3) high-voltage electrode (그림 3. 2. 2 참조)
(4) medium의 도면 (그림 3. 2. 1 참조)
(5) electrode와 medium의 조립도 (연구 결과물 참조)

(다) high-voltage generator의 구조
high-voltage는 chamber의 sensitive volume 내에서 발생한 전자를 signal electrode로 수집하여 전기적 신호를 발생한다. 이러한 high-voltage는 sensitive volume내에 electric field를 발생한다. 대부분의 electrometer는 이러한 high-voltage를 battery (고용량, 고가: 150만원) 또는 별도의 power supplier를 이용하여 발생한다.
(1) battery 종류별 high-voltage generator (표 3. 2. 7 참조)
(2) 250V 단일 battery
(3) 9V를 이용한 300V generator 회로
(4) 6V Charger 및 rechargeable battery를 이용한 170V Generator

(라) chamber assembly의 도면
(1) Holt/Marcus chamber의 비교 (부록 참조)
(2) housing assembly
(3) 작업도면 (PCB 도면, medium, cable, air-tight connection)
(4) 선형가속기 (Varian 2100C)의 blocking tray에 장착
(연구 결과물 참조)
(5) 선형가속기 (Varian 4/100)의 beam stopper에 장착
(연구 결과물 참조)

(마) air-tight type의 ionization chamber
2개의 PCB를 medium과의 접착시 공기의 유통을 막기위해서 각각의 접합면에 2mm*0.1mm의 홈을 제작하여 순간 접착제를 이용하여 고정한다. 이 chamber의 air-tight를 증명하기 위해서는 2-3개월의 실험 기산이 소요된다. 이유는 선형가속기의 radiation output이 약 0.2 - 0.3%의 uncertainty를 갖고있기 때문이다. 현재의

실험 data는 측정 data의 0.1%의 uncertainty (air-tight가 아닌 경우의 uncertainty (또는 stability)는 약 0.3% 이다)갖고 있는 것으로 추정되고, system 완성후 (2000년 3월 25일 현재 95% 완성) 강남 시립병원의 코발트 방사선원을 이용하여 확인 예정이다.

No	item	사용장비의 사양	본project의 목표사양	remark
1	sensitive volume	0.2 - 1.0cc	0.6cc	
2	high-voltage	300V	170, 330V	
3	medium material	acrylic, PMMA	acrylic	
4	gas	air	air	
5	electorde	graphite	Cu, Pb, Ag 도금	
6	Leakage Current	< 10-20fA	< 20fA	fAmp = 10^{-12}Amp

표 3. 2. 5. 상용의 parallel plate chamber와의 사양과 목표사양

No	item	사용장비의 사양	본project의 목표사양	remark
1	housing material	PMMA, Solid Water	Acrylic	
2	connector	Tri-axial	BNC	
3	chamber assembly size	30cm*30cm*1cm	30cm*30cm*10cm (backscattering medium)	
4	high-voltage source	from electrometer	(1) from 250V battery, (2) 9V, 6V battery	
5	seal type	ventilated	air-tight, ventilated	

표 3. 2. 6 방사선/재료적 비교사항

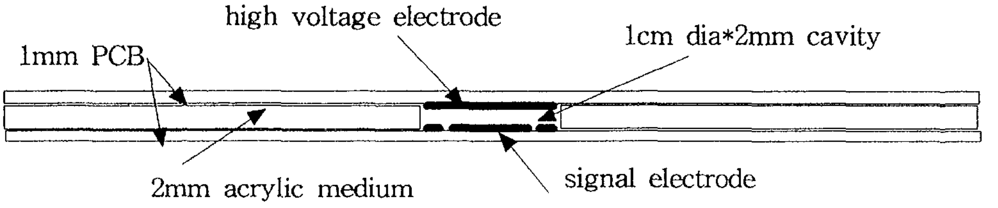
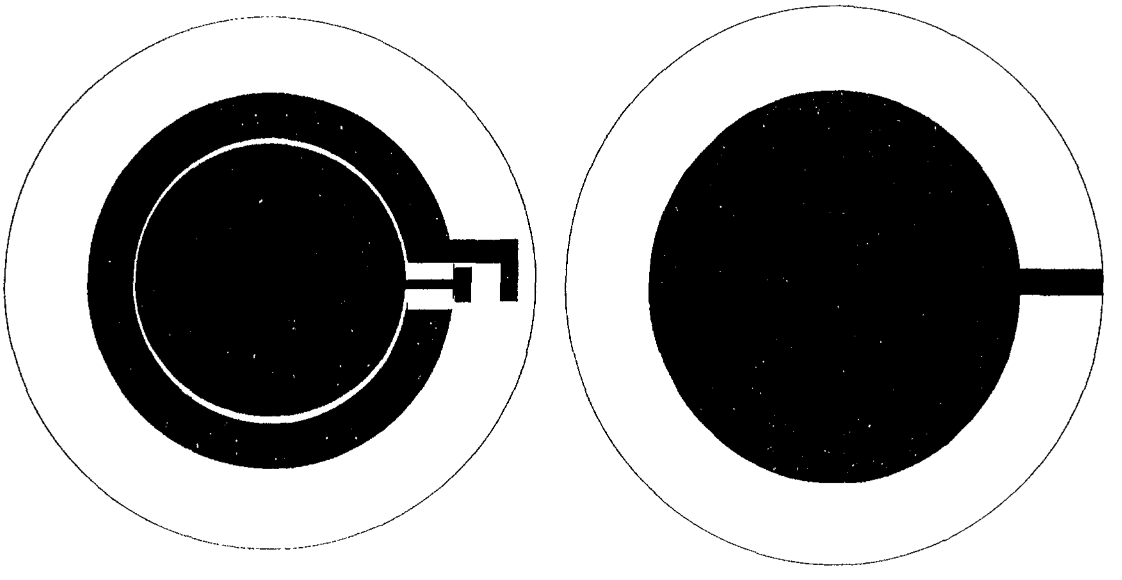


그림 3. 2. 1 참조 ionization chamber의 단면도



No	item	mm	remark
1	signal electrode의 반경	10mm	sensitive volume: 0.7cc
2	high-voltage electrode의 반경	12mm	
3	electrode간거리	2mm	
4	electrode type	Cu/Pb/Ag	100um thickness

왼편그림: signal, guard electrode
오른편 그림: high-voltage electrode

그림 3. 2. 2 signal electrode와 high-voltage electrode

No	items	사양	condition	remark
1	high-voltage	150 - 500V	(1) 전극종류 (2) 전극간 거리	max voltage는 cable의 max rating voltage에 의해 결정
2	recombination ratio	> 0.995	전계	recombination factor은 high-voltage와 dose rate의 함수
3	high-voltage의 protection	short-circuit 보호	100K safety resistor	장비 동작시 user 보호
4	high-voltage 발생방법	ripple: < 1%	(1) battery (2) transformer	75, 150, 300의 단계별 발생

표 3. 2. 7 High-voltage의 사양

3. parallel-plate ionization chamber의 확장성 (향후 계획)

(가) 제안된 구조

(1) stack type의 구조

(2) prototype의 stacked ionization chamber

(나) 제안된 구조의 필요성

(1) Electron Beam (4-25MeV) 의 percentage depth dose 측정용 setup

(2) charged particle (proton & alpha particles)의 bragg peak 측정

(다) small cavity의 liquid detector의 개발 가능성

(1) sensitive volume을 <1mm^{3}로 하여 resolution 증가

(2) air bubble을 최소화하기 위한 구조

(라) radiation survey meter로의 확장성

(1) sensitive volume을 1,000cc로 하여 survey meter 기능의 구현

(2) signal이 크므로 electrometer의 설계가 용이

라. electrometer의 구성

1. 일반적인 electrometer (dosemeter 또는 dosimetric system)의 사양

(가) system 구성

(아래 그림 3. 2. 3 참조)

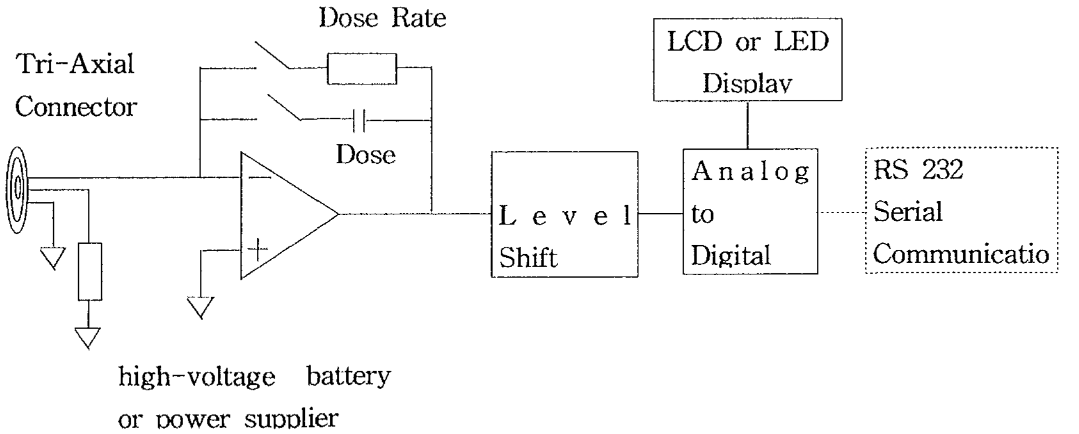


그림 3. 2. 3 치료 방사선기기 정도관리를 위한 electrometer의 Block Diagram
점선내의 sub-system은 option 사양임

(나) electrometer의 주요 parameter

No	Item	사양	응용분야
1	Radiation Type	x-ray, electron	health physics, 병원의 방사선과
2	Radiation Range	(1) R, R/h	health physics
		(2) cGy, cGy/min	병원의 방사선과
3	Accuracy	(1) +/- 10%	health physics
		(2) < +/- 0.5%	병원의 방사선과
4	Power	(1) battery	health physics
		(2) AC power	병원의 방사선과
6	Display 기법	LCD, meter	병원의 방사선과

2. 치료 방사선기기 정도관리를 위한 electrometer 사양

(가) 전기적 사양 (표 3. 2. 8 참조)

No	item	사양	비고
1	Measurement range	(1) charge: 19.999nc - 199.99nc (2) current: 199.0pA - 1999.99pA	
2	Resolution	0.005% of full scale	
3	Calibration accuracy (charge, current)	+/- 0.5%	
4	leakage current	< 30fA	
5	Time Constant	0.05 - 0.15sec	
6	High-voltage	360, 180, 90, 45, 22.5	
7	High-voltage accuracy	1V	
8	High-voltage impedance	> 1MΩ	
9	Input Power	100/200V	

표 3. 2. 8 참조 전기적 사양 (주로 NE Type 2620 dose/dose-rate meter 기준)

(나) System Block Diagram (아래 그림 3. 2. 4 참조)

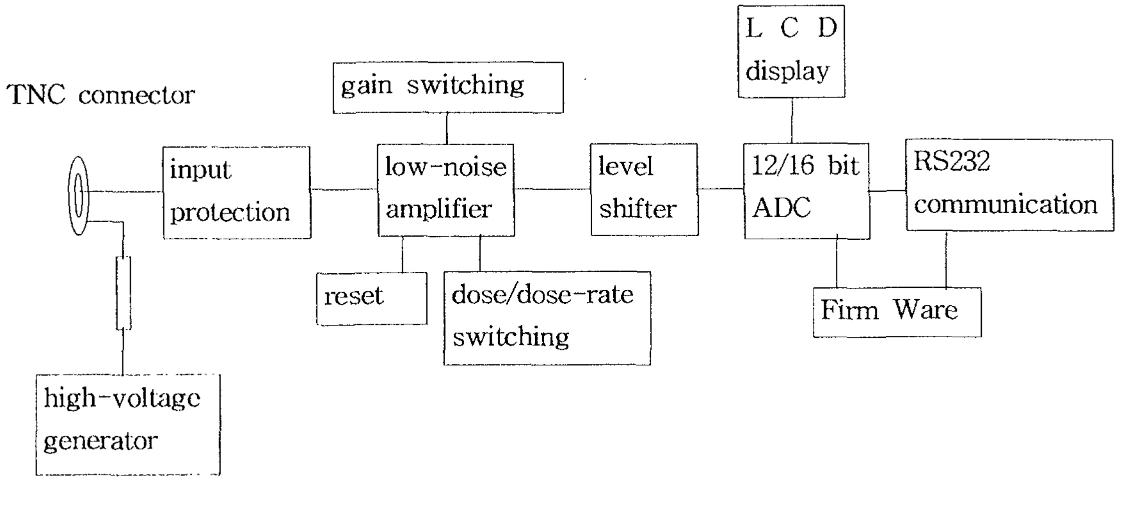


그림 3. 2. 4 System Block Diagram

(다) 세부 내용

(1) a single gain pre-amplifier (그림 3. 2. 5 참조)
(2) three step gain pre-amplifier (그림 3. 2. 6 참조)
(3) Analog-to-digital converter (그림 3. 2. 7 참조)
(4) RS232 serial communication (그림 3. 2. 8 참조)
(5) Computer Interface (그림 3. 2. 9 참조)

(라) detailed schematic diagram

(1) electrometer A (10bit ADC)
(2) two channel electrometer B (>16bit ADC)
(3) two channel electrometer C

3. 저에너지 또는 radiation survey meter의 electrometer (향후 계획)

(가) 필요성

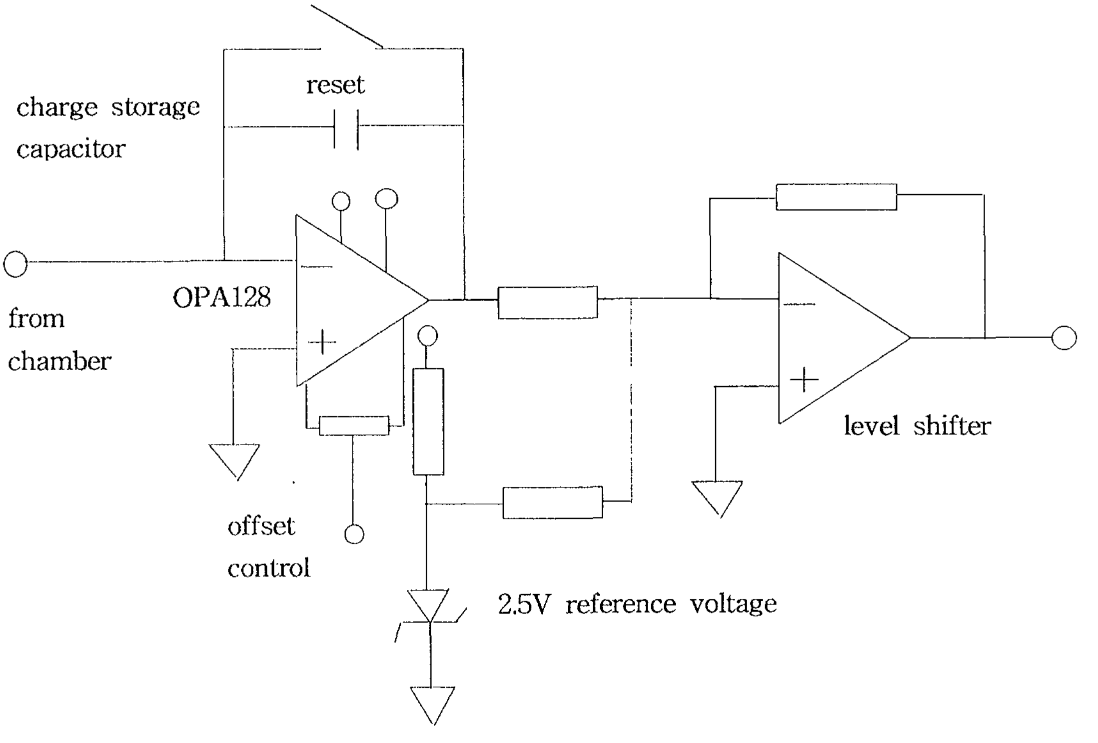


그림 3. 2. 5 one-step의 OPA128을 이용한 preamplifier의 회로도

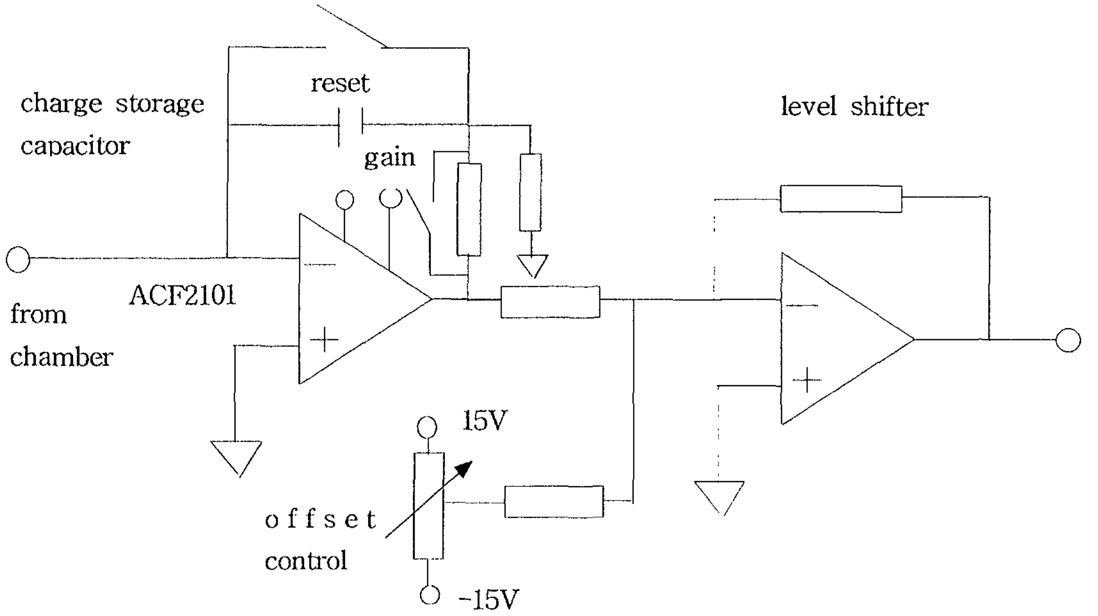


그림 3. 2. 6 Three-step gain preamplifier
1st gain: 20bit resolution
2nd gain: gain switch off and 16-bit reolustion
3rd gain: gain switch off and 16-bit resolution

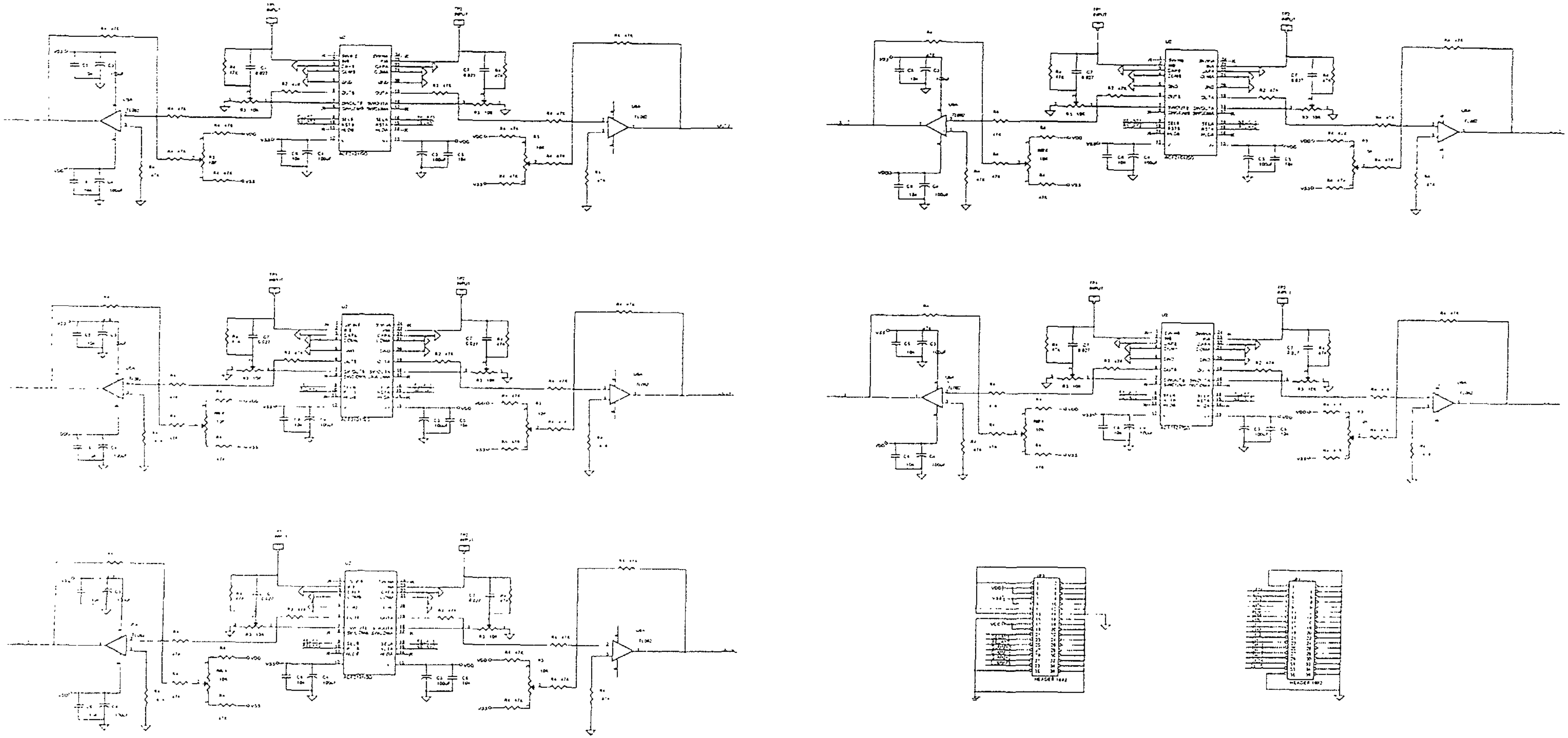


그림 3. 2. 7 8-channel pre-amplifier

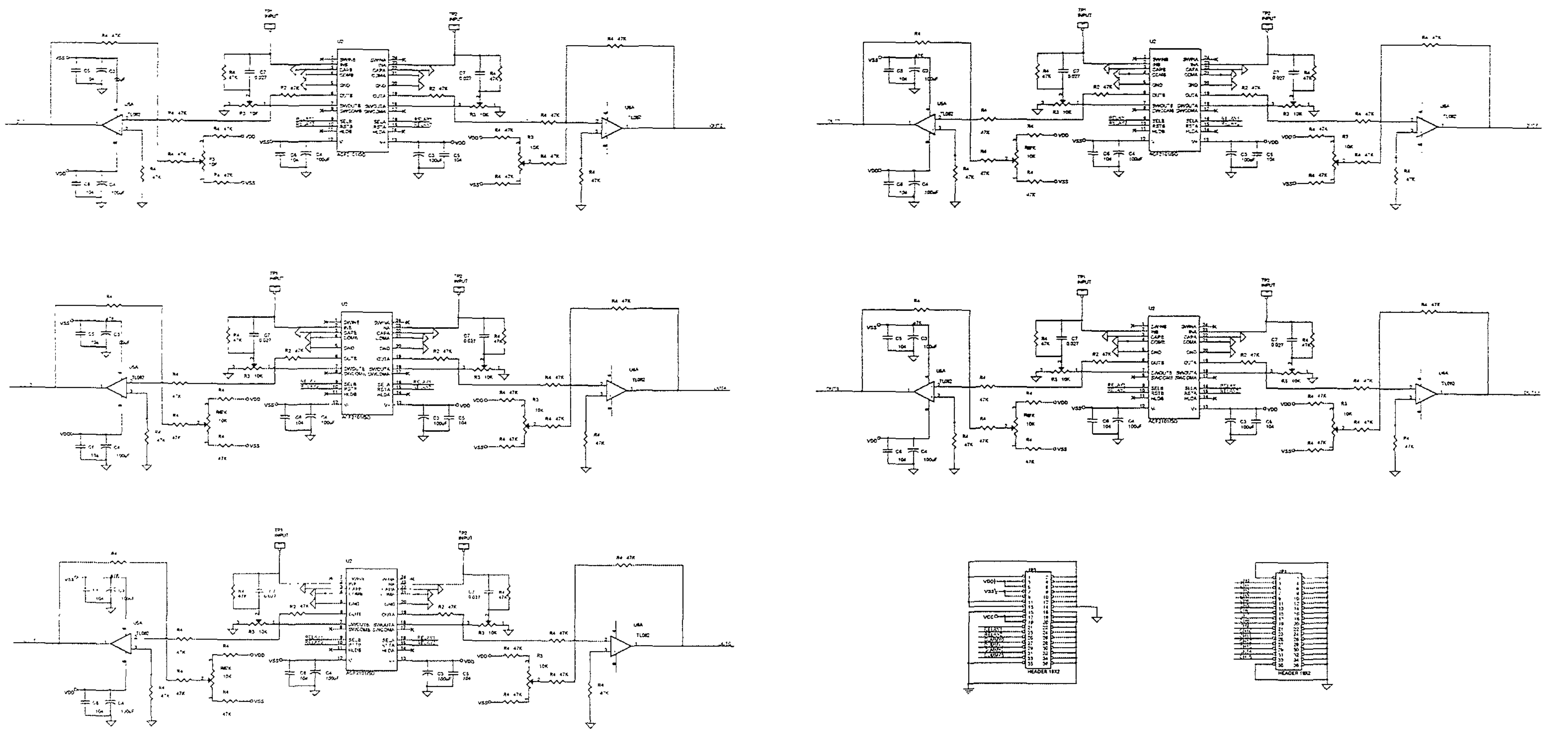


그림 3. 2. 8 one-channel pre-amplifier와 ADS1210 (ADC converter) 의 회로도

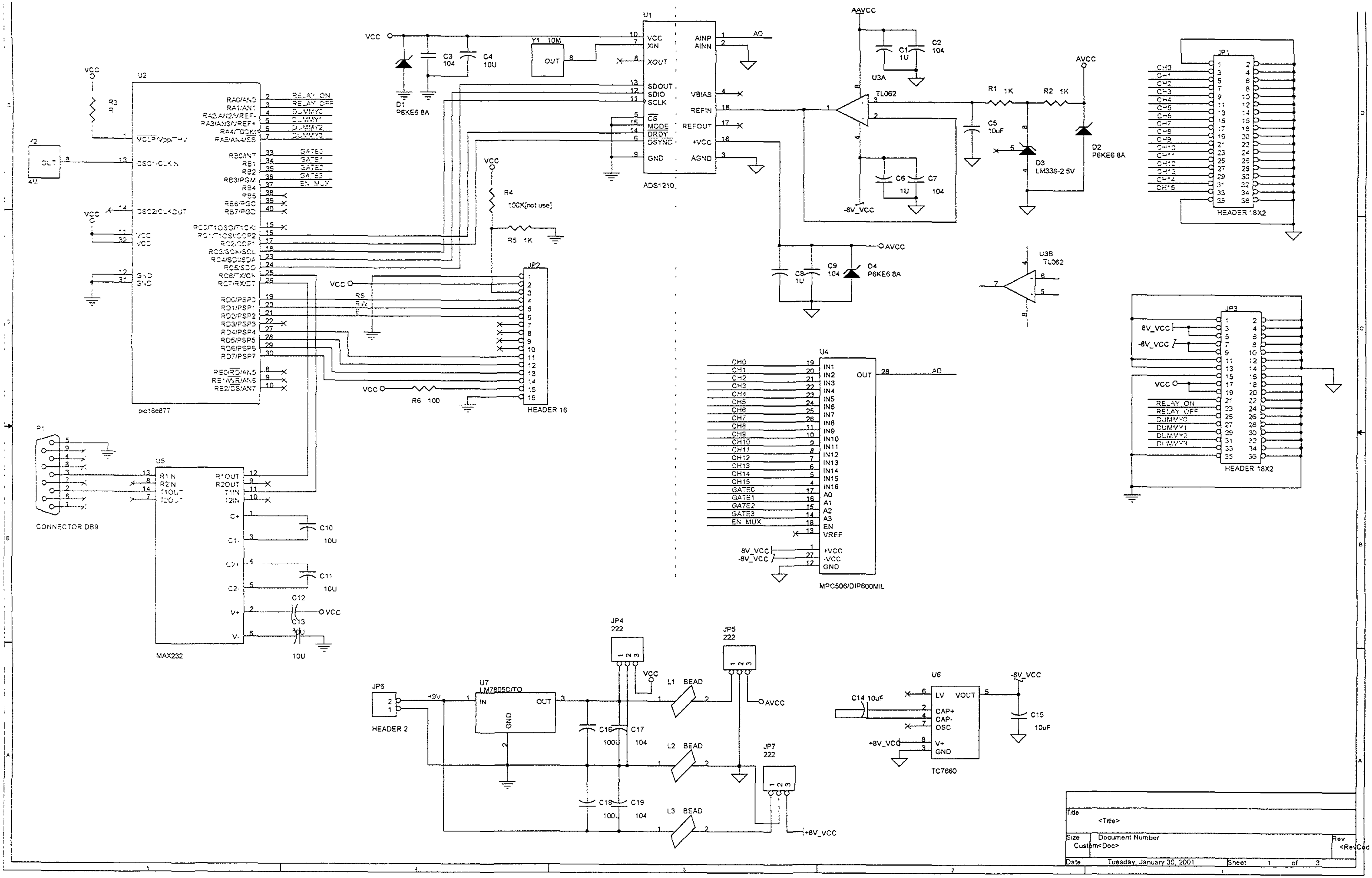


그림 3. 2. 9 Computer Interface

마. Dosimetric system (ionization chamber과 electrometer) 의 구성 (일반 사양)

1. Calibration 용도

Calibration 용도의 dosimetric system은 선형가속기의 방사선 출력을 일반적으로 표준 setup (100cm SSD, 10cm*10cm, 240MU/min, water phantom, water phantom 내부의 특정 깊이 (5, 7, 10cm)에서 1MU = 1cGy로 조정하기 위한 절차로 chamber, electrometer, cable등이 표준기관에서 certify 되어야한다. 이를 위해서는 표준 방사선원과 표준 capacitor가 필요하다. 이러한 calibration용도의 dosimetric system은 고가이고 (20,000 - 40,000US$), 고도의 표준화기술이 필요하므로, 이러한 고도의 기술은 본 project 종료후 계속할 추진할 예정이다.

이의 개략적인 사양은 다음 표와 같다.

No	항목	사양	remark
1	radiation type	X-ray, electron beam	MeV, MV range
2	radiation range	1 - 30MV X-ray	
3	recombination factor	>0.995	
4	stem effect	<0.5%	
5	stability	<0.2%	
6	high-voltage	150, 300V	
7	radiation amount	10 - 1000cGy	at SSD=100cm
8	precision	0.001nC	
9	display digit	3 1/2 (또는 4 1/2)	

2. 정도관리용

Calibration용도의 dosimetric system에 비해서 정도관리용 dosimetric system은 선형가속기의 repeatibility (또는 stability 또는 reproducibility)를 측정한다. 이는 주로 선형가속기의 일일 또는 월별 정도관리의 일환으로 시행한다. 일일 전도 관리로 치료방사선과에서 치료방사선사가 장비를 setup 하고 측정한다. 따라서, 일일 정도관리 절차는 간단하면서도 정확하여야한다. 주로 일어나는 setup상의 문제점은 SSD setup의 부정확성 (1mm의 불확실성은 +/- 0.2%의 오차를 유발), 선형가속기의 repeatibility (Varian, Siemens의 선형가속기의 경우 ~0.2%, Philips 의 선형가속기의 경우 ~0.4%이다. 그러나, 5년이상된 선형가속기는 +/- 1% 이상이 보고 되고 있다. 실지로 모병원의 Varian 6/100 선형가속기는 "+/- 2% 이상"의 repeatibility를 보고하고 있다).

개략적인 정도관리의 사양은 다음과 같다.

No	항목	사양	remark
1	radiation type	X-ray, electron beam	MeV, MV range
2	radiation amount	100, 200cGy	표준 setup
3	측정 사양	output factor (wedge factor, FSD)	
4	측정횟수	3 - 5회	일일정도관리
5	stability	< 0.5%	
6	display digit	2 - 3 digit	
7	uncertainty	< 0.5%	at SSD=100cm
8	linearity	~ 1%	

(가) 일반적인 정도관리용 장비

- phantom : Solid water™, White Water™ (8,000 - 10,000 US$)
- ionization chamber: Farmer chamber (3,000 US$)
- electrometer: Kethley or NA electrometer (10,000 - 40,000US$)
- setup 시간: 20분 - 30분
  (electrometer의 최저 warmup time은 15min)

(나) 기술적인 parameter

- 국내의 phantom material은 0.5%내로 도입용 material과 같은가?
- ionization chamber assembly는 reliable 한가?
- electrometer는 < 0.5%의 정확도?
- setup 시간는 15분이내인가?
- 선형가속기 치료실내의 noise로부터 영향은?
- RS-232 communication은 최대 40meter에서 가능한가?

바. 정도관리용 Dosimetric system의 구성

Dosimetric system을 개발하기 위해서 현재의 치료방사선과의 정도관리 protocol을 검토한 결과 1ionization chamber와 electrometer는 다음의 조합이 필요하다. 이 각각의 조합을 위해서 3 종류의 dosimetric system을 개발하게되었다. 세부 내용은 다음의 표와 같다.

No	대학병원의 일반적인 정도관리 system의 내용	본연구에서 개발하고자 하는 system		
		System A	System B	System C
ionization chamber	Farmer chamber diode detector	Parallel Plate	Parallel Plate	Parallel Plate
electrometer	Keithley or NE electrometer	10 bit ADC electrometer	10 bit ADC electrometer	18 bit ADC electrometer
high-voltage	electrometer 내장 (교체시 150만원)	250V 단일 battery	9V battery	6V rechargeable battery
cable	Tr-axial cable (150만원)	bi-axial cable	bi-axial cable	bi-axial cable
computer interface (serial communication)	option (새로운 장비는 보유)	No	No	RS232 Interface
phantom material	Solid Water Phantom White Water Phantom Polystyrene Phantom	acrylic plate	acrylic plate	acrylic plate

(사) "System A" 구조의 Dosimetric System의 구성은 다음과 같다.

(1) ionization chamber (air-ventilated type)
(가) parallel plate chamber
① sensitive volume: 0.6cc
② signal, gurad, high-voltage electrode의 구현
③ medium의 구조
㉮ acrylic plate : 20cm*20cm*2mm
㉯ cable-inserted type
(나) electrometer
① preamplifier
② 10 bit ADC
③ LCD display
(다) 250V high-voltage generator
(라) bi-axial cable과 BNC connector

(2) 10-bit ADC electrometer
(가) preamplifier
(나) 4bit LCD display
(다) 2-channel electrometer

(3) 주요 parameter의 측정결과
(가) staibility: ~0.3%
(나) mechanical accuracy: <0.5mm
(다) Setup Time: < 10 min

(아). Dosimetric system B (air-tight chamber + 300V batt + 10bit electrometer)

(1) ionization chamber (air-tight type)
(가) parallel plate chamber (air-tight만 제외하고 System A와 같음)
(나) 9V의 battery를 이용한 303 high-voltage generator

(2) electrometer (System A와 같음)

(3) 주요 parameter의 측정결과
(가) staibility: 0.15% (air-tight의 검증)
(나) 상용의 9V battery 이용의 잇점

(자) Dosimetric system C (air-tight chamber + 6V batt + 18bit electrometer + PC)

(1) ionization chamber (air-tight type)

(가) parallel-plate chamber (air-tight만 제외하고 System A와 같음)

(나) 6V의 battery를 이용한 170V high-voltage generator

(2) electrometer

(가) ACF2101 low-noise amplifier (1-2 channel, 8 channel)

(나) ADS1210 (23-bit resolution)의 ADC 구현

(다) RS-232 interface

(라) Paperless dosimetric system의 구현

(3) 주요 parameter의 측정결과

(가) staibility: < 0.1%

(나) resultion: 0.1nC

(다) leakage current: <20fA

5 절 연구 결과 및 결과물

1. 선형가속기의 일일/월별 정도관리 사양표 (방사선관련 사항)

가 일일정도관리 사양 (방사선 관련사항만 포함)

(1) X-ray beam (Varian 2100C의 선형가속기에 적용예)

㉮ 일일정도관리setup protocol (표 3.5.1 참조)

㉯ 일일정도관리setup protocol에 의한 측정 결과 (표 3.5.2 참조)

(2) Electron Beam

Electron의 setup protocol은 X-ray beam의 일일정도관리 setup protocol과 다음 사항을 제외하고는 같다.

① Cone setup

② SSD=100cm

나 월별정도관리 사양 (방사선 관련사항만 포함)

(1) X-ray beam (Varian 2100C의 선형가속기에 적용예)

㉮ 일일정도관리의 procedure를 반복

㉮ 월별정도관리 setup protocol (표 3.5.3 참조)

㉯ 월별정도관리 setup protocol에 의한 측정 결과 (표 3.5.4 참조)

(2) Electron Beam

Electron의 월별정도관리 setup protocol은 X-ray beam의 setup protocol과 다음 사항을 제외하고는 같다.

① Cone setup (10cm*10cm, 30cm*30cm)

② SSD=100cm

③ ESSD 대신 VSD 계산

No	측정 procedure	comments	remark
1	ionization chamber와 electrometer를 연결한다. electrometer는 reset 한다.		electrometer warmup procedure
2	선형가속기를 warmup하고 500MU의 low energy의 electron beam (낮은 에너지에서 높은 에너지로 증가하면서) 조사하후, X-ray beam를 100MU (3회) 조사한다.	선형가속기가 warmup 되어있으면 이단계는 skip	선형가속기의 warmup
3	electroemter의 zero drift 조사	reset을 off후 1분후의 redaing 값을 기록한다	0.004V 이하 (주) 1
4	10회의 방사선 조사 (10cm*10cm, SSD=67.5cm, 100 or 200MU)	data 기록후 average와 standard deviation을 계산/기록한다	warmup이 충분하지않으면, 초기의 2-3회 reading은 계산에서 제외한다
5	electrometer를 resetgksgn 100MU의 방사선조사	방사선조사후 1분후에 reading값을 기록한다	0.004V 이하 (주 1)

(주) feedback capacitor의 값이 0.027uF (27nF)이므로 1V는 27nC의 전하에 해당된다. 그러므로, 0,004V = 0.11pC 이다

표 3. 5. 1 X-ray 측정을 위한 일일정도관리 Setup protocol

No	Date	Measurements (10 회 측정)	avg	std (std/avg)*100	TPC	Remark
1	10/23 2000	0.618, 0.618, 0.618, 0.613, 0.613, 0.613, 0.618, 0.618, 0.618, 0.618,	0.618	<0.2%	1.002	0.619
2	10/24 2000	0.616, 0.61, 0.616, 0.613, 0.613, 0.613, 0.619, 0.618, 0.618, 0.618,	0.617	<0.2%	1.002	0.619
3	10/28 2000	0.619, 0.614, 0.618, 0.616, 0.614, 0.614, 0.618, 0.617, 0.618, 0.619,	0.619	<0.2%	1.002	0.619

표 3. 5. 2 일일정도관리 Setup protocol에 의한 측정 결과의 예

표 3. 5. 3 X-ray 측정을 위한 월별정도관리 Setup protocol

No	측정 procedure	comments	remark
1	ionization chamber와 electrometer를 연결한다. electrometer는 reset 한다.		electrometer warmup procedure
2	선형가속기를 warmup하고 500MU의 low energy의 electron beam (낮은 에너지에서 높은 에너지로 증가하면서) 조사하후, X-ray beam를 100MU (3회) 조사한다.	선형가속기가 warmup 되어있으면 이단계는 skip	선형가속기의 warmup
3	electroemter의 zero drift 조사	reset을 off후 1분후의 reading 값을 기록한다	0.004V 이하
4	10회의 방사선 조사 (10cm*10cm, SSD=67.5cm, 100/200MU)	data 기록후 average와 standard deviation을 계산/기록한다	warmup이 충분하지않으면, 초기의 2-3회 reading은 계산에서 제외한다
5	electrometer를 resetgksgn 100MU의 방사선조사	방사선조사후 1분후에 reading값을 기록한다	0.004V 이하
6	FSD (5cm*5cm, 10cm*10cm, 20cm*20cm, 30cm*30cm)을 측정	10cm*10cm의 data로 normalization	physics beam data와 비교
7	Tray Factor 측정	10cm*10cm의 data로 normalization	physics beam data와 비교
8	Wedge Factor 측정 (15, 30, 45, 60도)	10cm*10cm의 data로 normalization	physics beam data와 비교
9	Elongated Field Effect (5cm*20cm, 20cm*5cm)	2개의 data의 비 계산	
10	Dose Rate Effect (80, 160, 240, 320, 400cGy.min)	240cGy/min의 data로 normalization	physics beam data와 비교
11	Timer Effect (200MU와 4*50MU의 차이)	2 data의 비 계산	

표 3.5.4 X-ray 측정을 위한 월별정도관리 Setup protocol의 측정 sheet

No	Item	측정 procedure	comments
1	재현성	0.618, 0.618, 0.618, 0.613, 0.613, 0.613, 0.618, 0.618, 0.618, 0.618,	avg = 0.618 std < 0.2%
2	zero drift in V	0.004V (cuurent 또는 전하로 변환시 표 3.5.1참조)	
3	leakage current in V	0.004V	
4	FSD	0.883, 1.000, 1.169, 1.333	S_c & S_p 포함
5	Tray Factor	0.996	
6	Wedge Factor	0.822, 0.695, 0.537, 0.455	
7	Elongated Effect	1.016 (4cm*10cm, 10cm*4cm)	
8	Dose Rate Effect	< 0.3%	
9	Timmer Effect	< 0.2%	

2. ionization chamber의 설계/제작

(가) air-ventilated ionization chamber

① PCB를 이용한 electrode 구현 (그림 3.5.1 참조)
② PCB 와 acrylic plate와의 조립 도면 (그림 3.5.2 참조)
③ Chamber의 assembly (그림 3.5.3 참조)
④ Backscattering medium의 구현 (그림 3.5.4 참조)
⑤ Buildup Plate (그림 3.5.5 참조)
⑥ 조립된 chamber assembly (그림 3.5.5 참조)

(나) high-volatge generator

① 단일 battery를 이용한 high-voltage generator (그림 3.5.3 참조)

㉮ 장점
- high-volatge circuit가 간단
- reliability 증가
- battery 수명: 6개월

㉯ 단점
- battery 교체시 전문가 필요

㉰ 보완
- 다음의 사용의 9V battery 또는 rechargeable battery 이용

② 9V battery를 이용한 high-voltage generator (그림 3.5.6 참조)

㉮ 장점
- high-volatge circuit가 간단
- reliability 증가
- battery life: 6 hours
- 330V의 고출력

㉯ 단점
- high-volatge generator의 circuit가 복잡

㉰ 보완
- 다음의 6V rechargeable battery 이용

③ 6V rechargeable를 이용한 high-voltage generator (그림 3.5.7 참조)

㉮ 장점
- high-volatge circuit가 간단 (LCD back-light 용)
- reliability 증가
- 한번 충전후 battery life: 20 hours (30mA 전류 소모)
- 170V의 고출력 (간극이 2mm 이므로 recombination factor: > 0.995)

㉯ 단점

- high-volatge generator의 circuit가 복잡

(다) Connection cable/Connector (그림 3.5.8 참조)

3. electrometer 설계/제작

(가) System A 용 Electrometer (그림 3.5.9 참조)

① channel 수: 2
② preamplifier: OPA128이용의 low-noise charge-to-voltage converter (CVC)
③ ADC resolution: 10 bit (최소 reading: 0.004V ==> 0.11pC)
④ Display: 3 1/2 digit display
⑤ power supplier: 100/200V
⑥ leakage current: 200fAmp

(나) System B 용 Electrometer (그림 3.5.10 참조)

① channel 수: 5
② preamplifier: OPA128이용의 low-noise charge-to-voltage converter (CVC)
③ ADC resolution: 10 bit (최소 reading: 0.004V ==> 0.11pC)
④ Display: 3 1/2 digit display
⑤ power supplier: 100/200V
⑥ leakage current: 100fAmp

(다) System C 용 Electrometer

① channel 수: 2 (최대 12)
② preamplifier: ACF2101이용의 CVC (그림 3.5.12 참조)
③ Gain Switching: 2
④ ADC resolution: 18 bit (그림 3.5.12 참조)
⑤ Display: 3 1/2 digit display (그림 3.5.13 참조)
⑥ power supplier: 100/200V
⑦ leakage current: 20fAmp
⑧ RS232 Serial Data Communication (그림 3.5.14 참조)
⑨ User Interface (그림 3.5.16 참조)

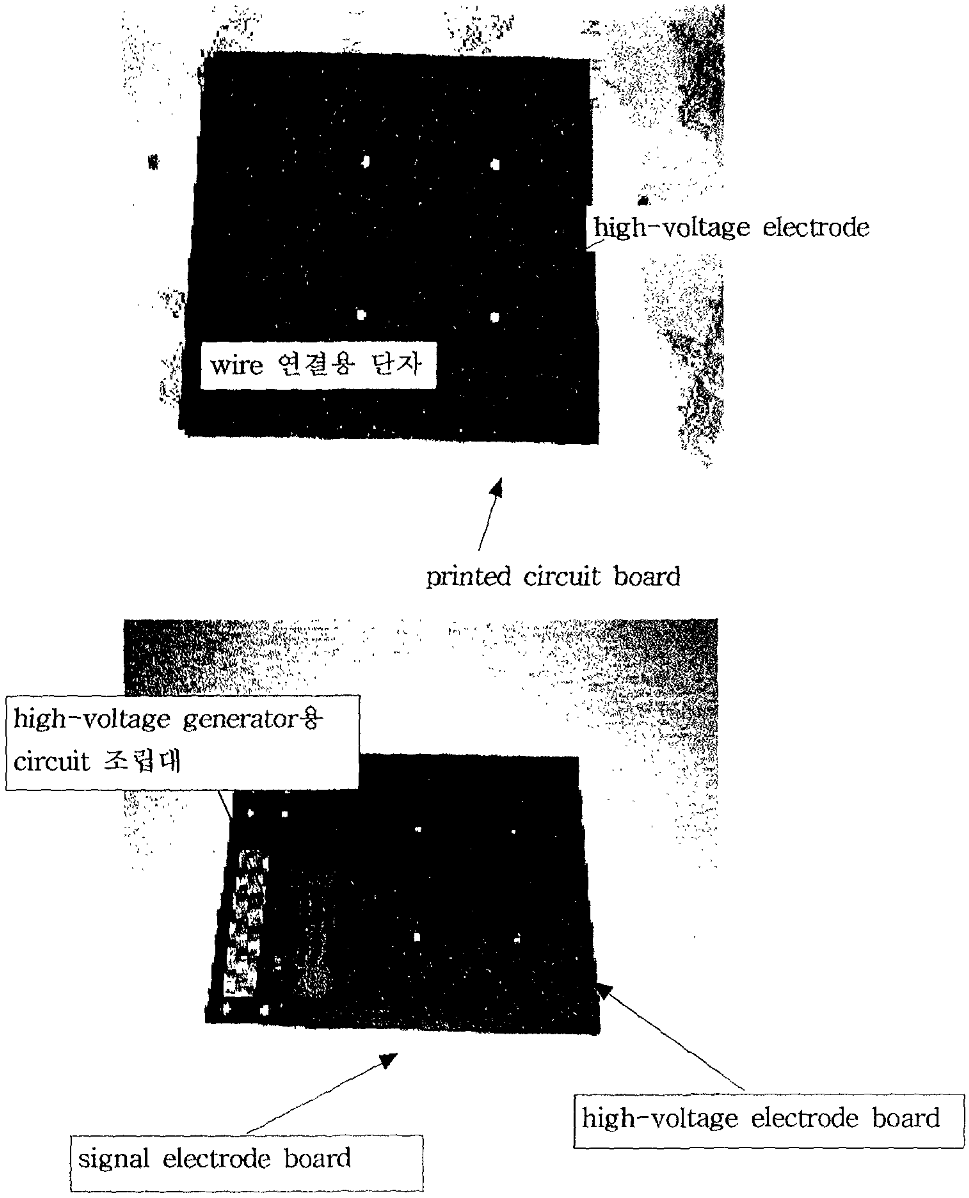


그림 3.5.1 PCB를 이용한 electrode의 구현

그림 위: 반경 1cm의 high-voltage electrode를 printed circuit board (PCB)를 이용한 구현

그림 아래: medium, high-volateg electrode, signal electrode의 PCB가 조립된 그림

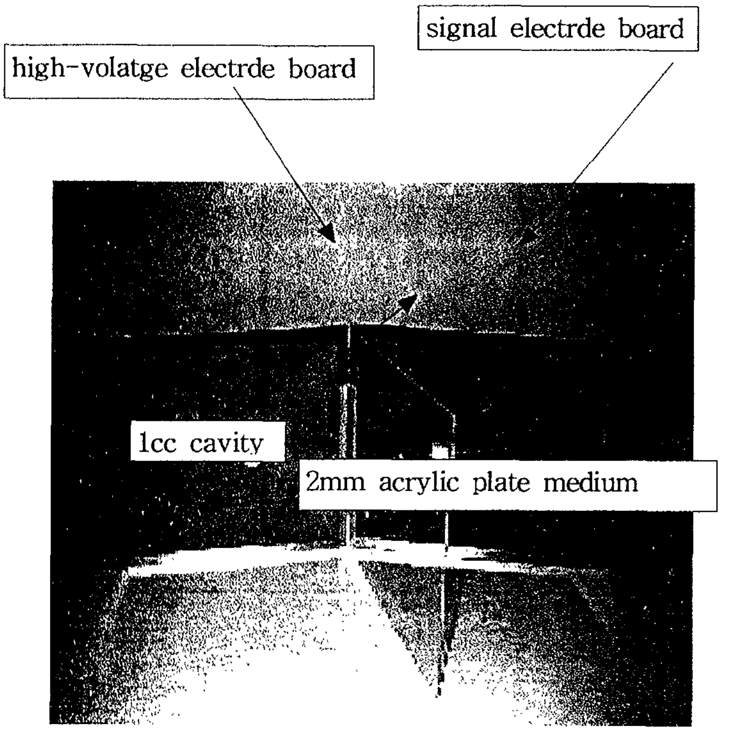


그림 3.5.2 PCB와 acrylic plate와의 조립

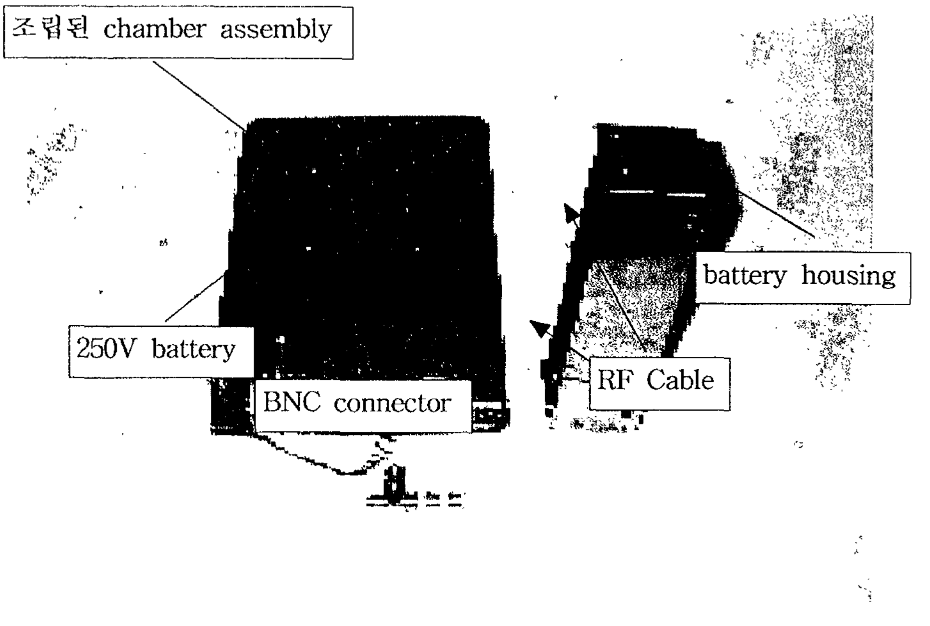


그림 3.5.3 Chamber Assembly

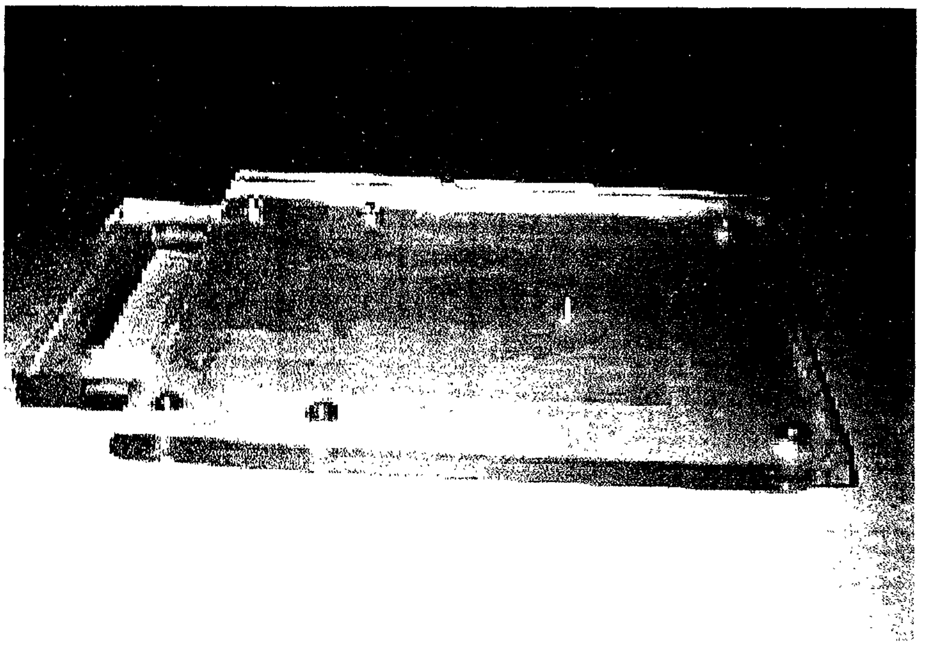


그림 3.5.4 Backscattering Medium

Ionization chamber의 재현성을 높이기 위해서는 충분한 backsacttering medium (5cm이 필요)과 chamber assembly의 운반을 편하게 하기위해서 handle을 겸하였다

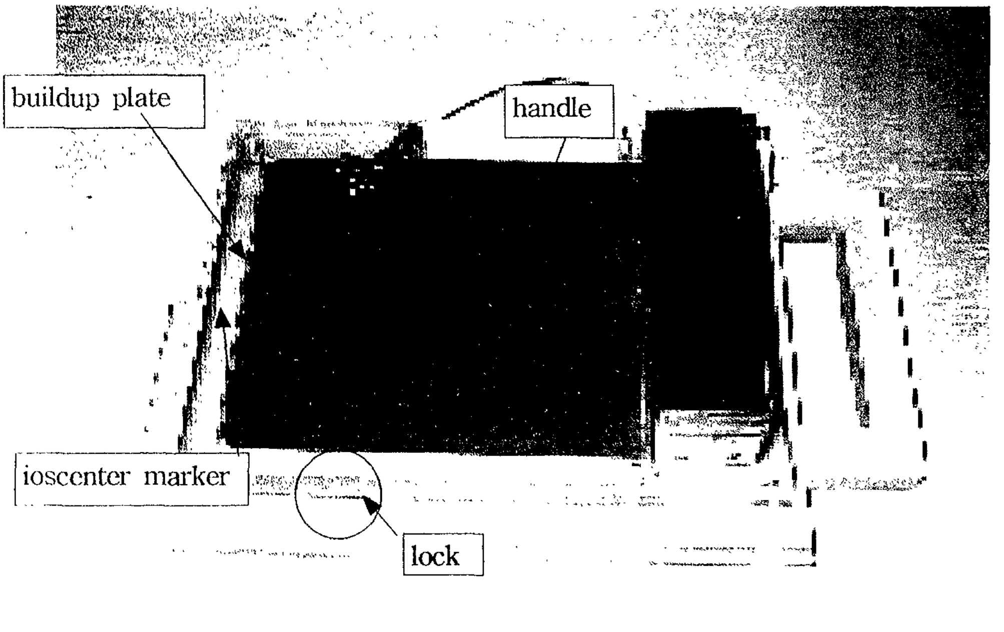


그림 3.5.5 조립된 chamber assembly

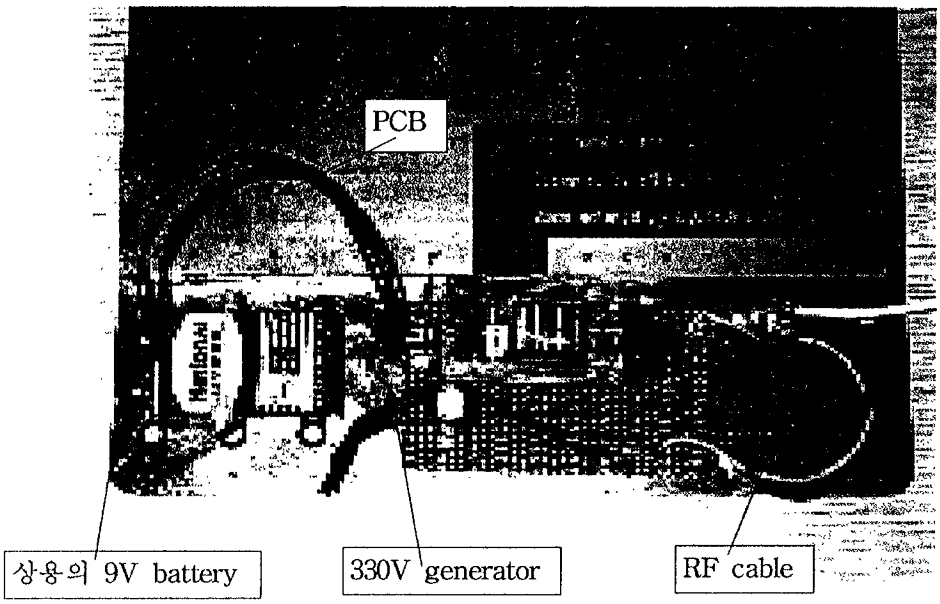


그림 3.5.6 상용의 9V battery를 이용한 high-voltage generator

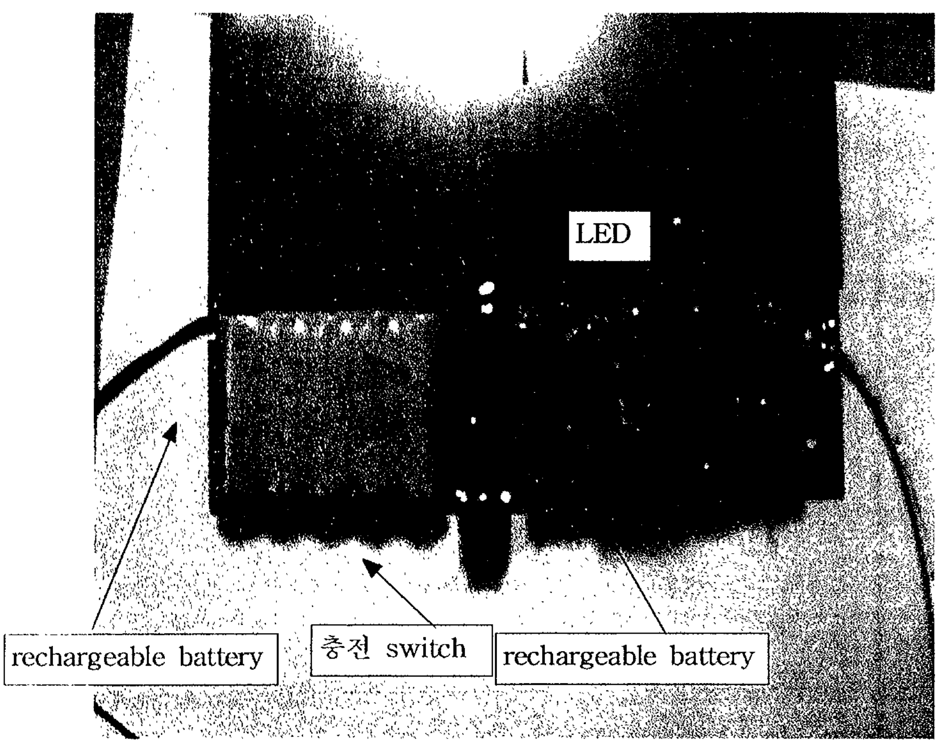


그림 3.5.7 상용의 6V rechargeable battery를 이용한 high-voltage generator (출력: 170V, life: 20 hours)

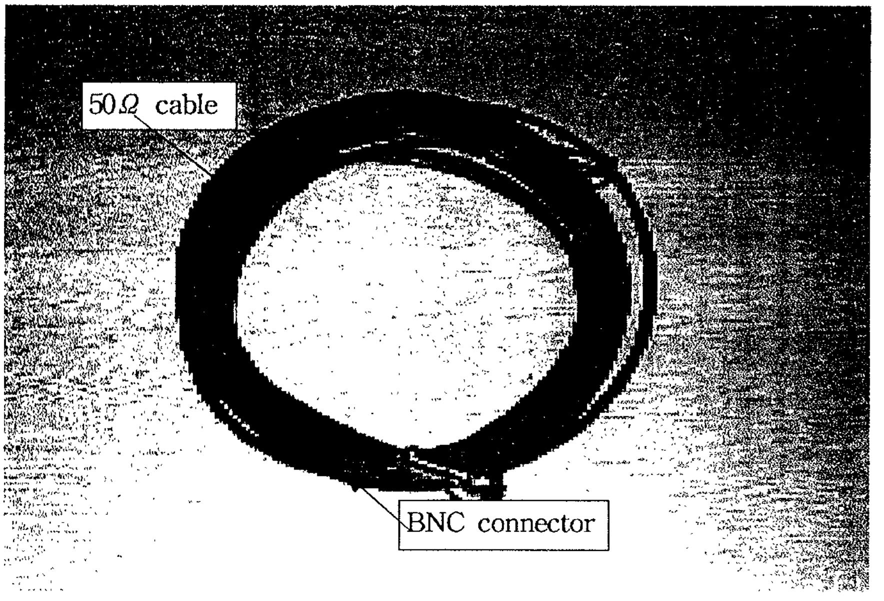


그림 3. 5. 8 국산의 Coaxial RF cable

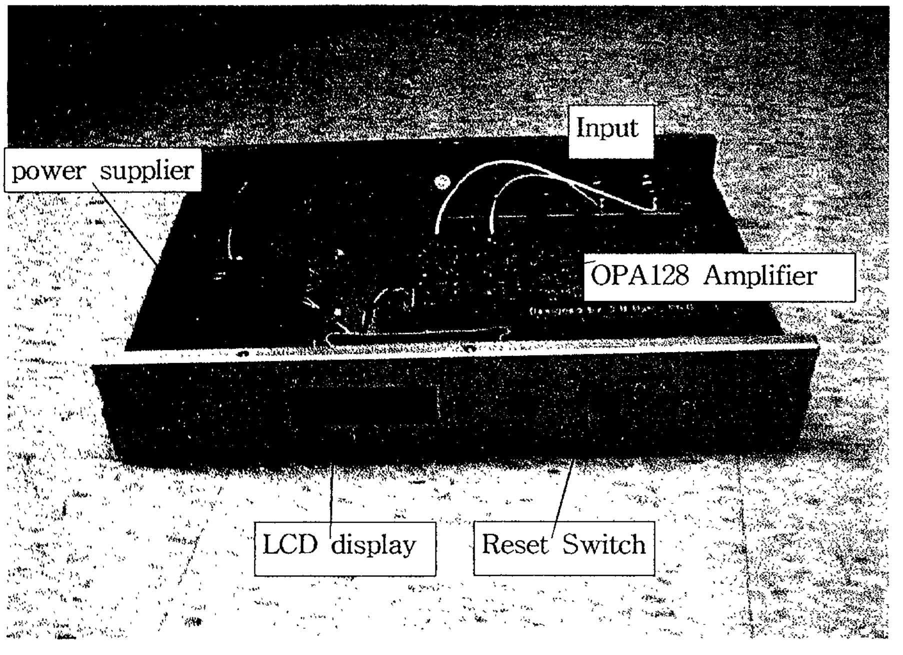


그림 3.5.9 System A 용 Electrometer
10-bit ADC, LCD Display, 2 channel (최대 5 channels)
100/200 free voltage regulator

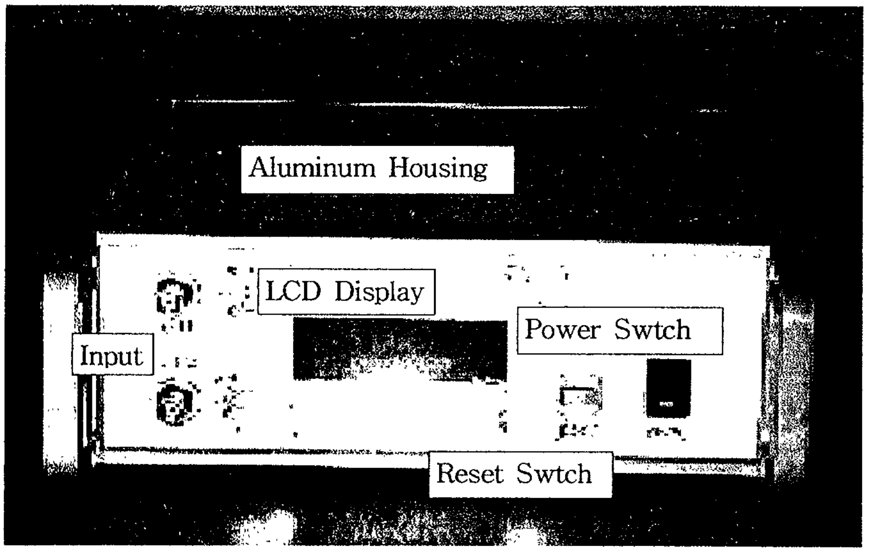


그림 3.5.10 System B 용 Electrometer

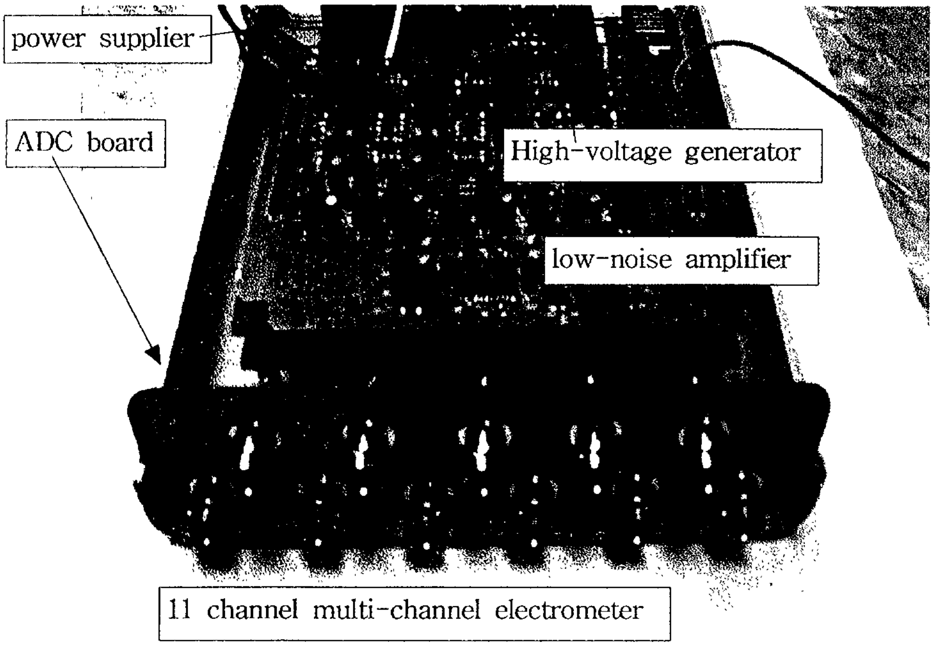


그림 3.5.11 System C 용 Electrometer의 구성도
ACF2101 low-noise CVC, ADS1210 ADC, a single power
max 16 channels, RS 232 serial board (뒷면 PCB)

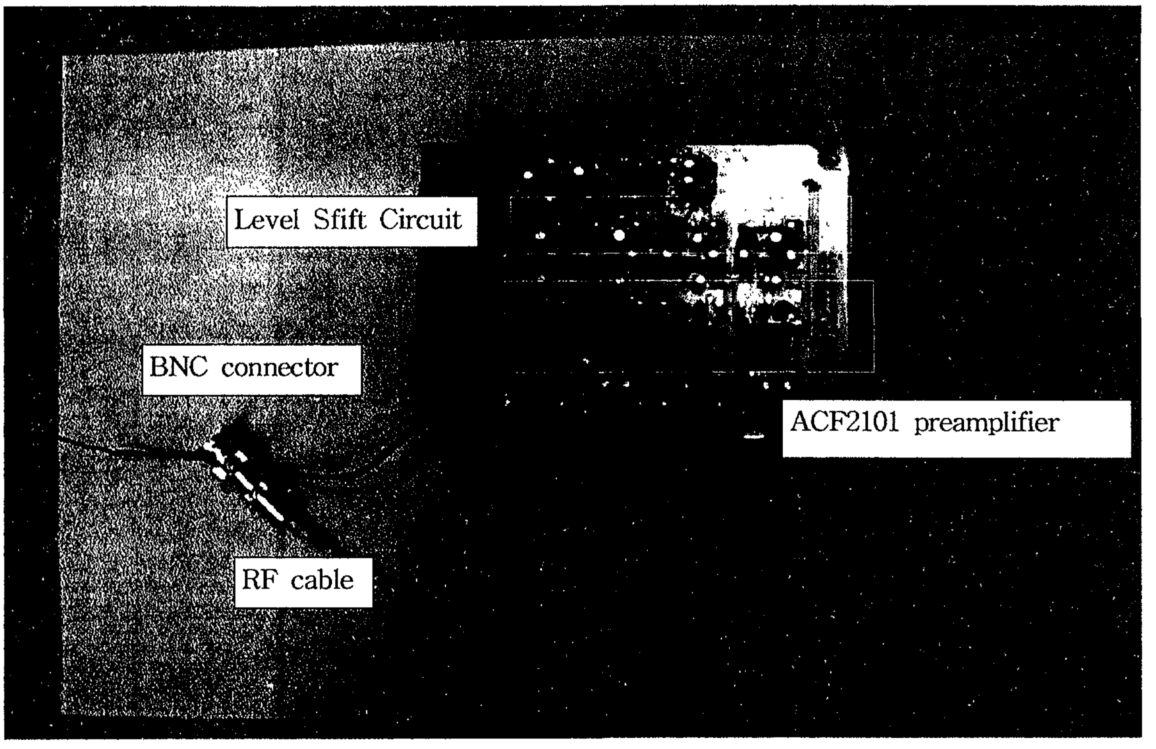


그림 3. 5. 12 preamplifier의 조립도면 (ACF2101이용의 CVC)
그림상에는 1 channel만 RF cable이 연결된 상태임

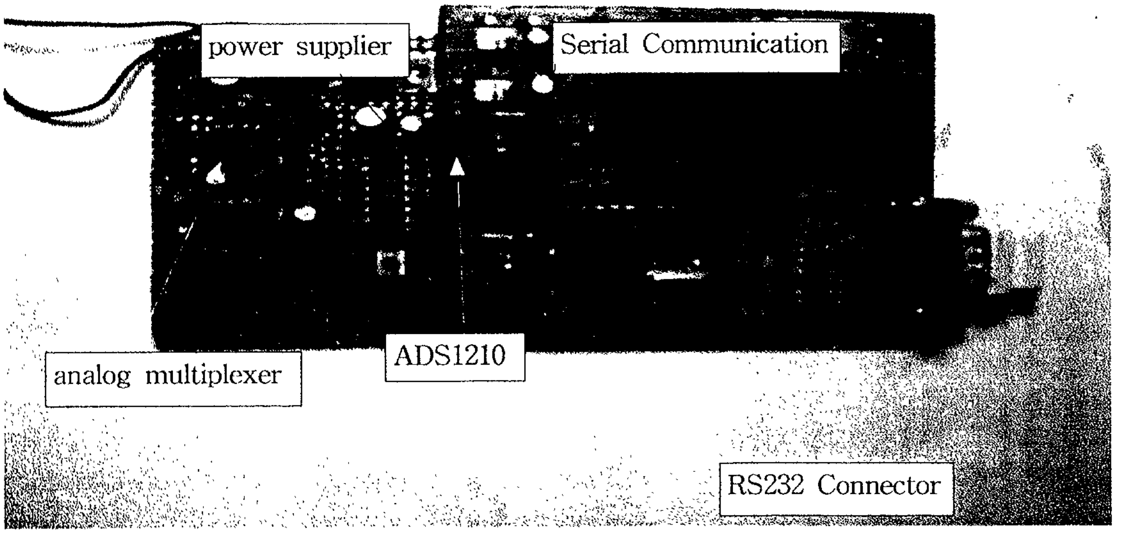


그림 3.5.12 ADC board (ADs1210 23-bit resolution)
RS232 serial communication, 16-channel analog multiplexer single power supplier

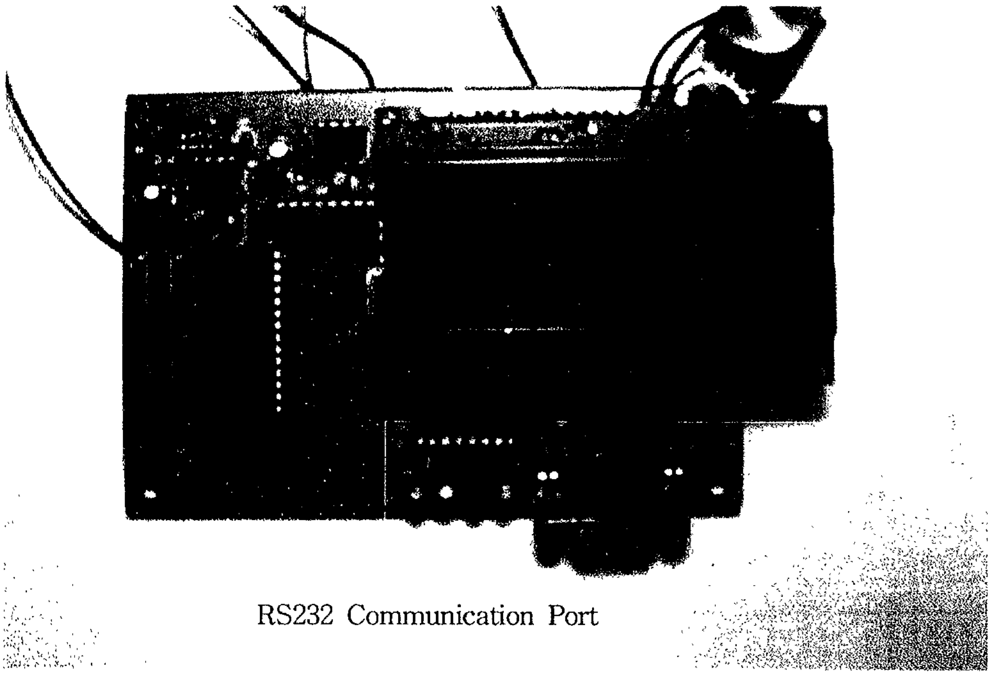


그림 3. 5. 13 Display Module: 3 1/2 digit LCD display

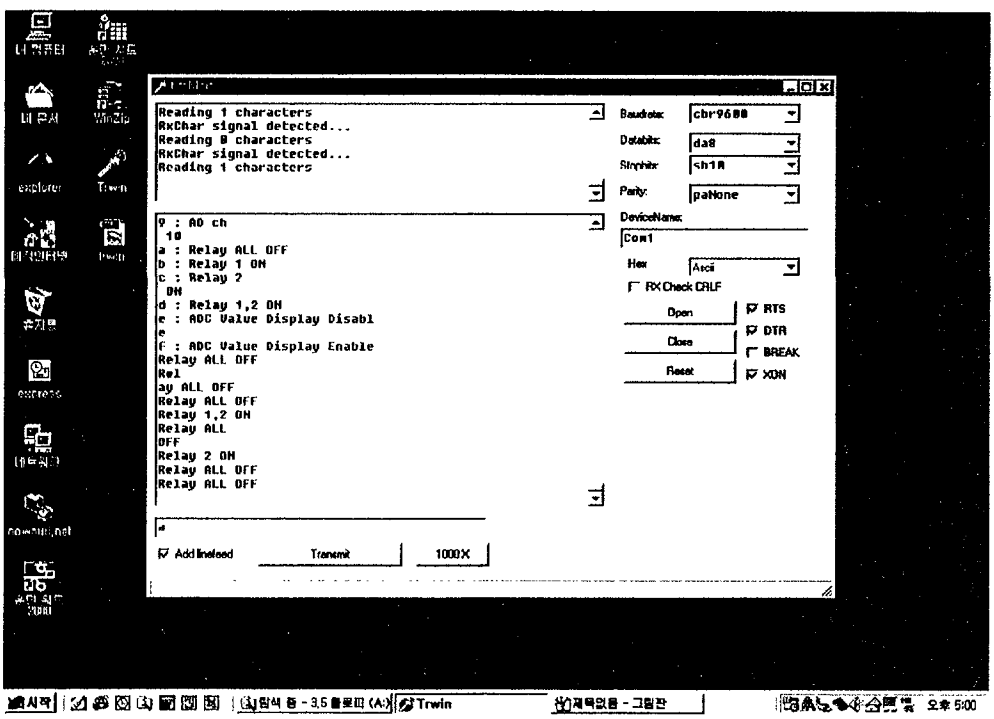


그림 3. 5. 14 RS232 Serial Data Communication을 위한 user interface Visual C++ version 6.0으로 progarmming

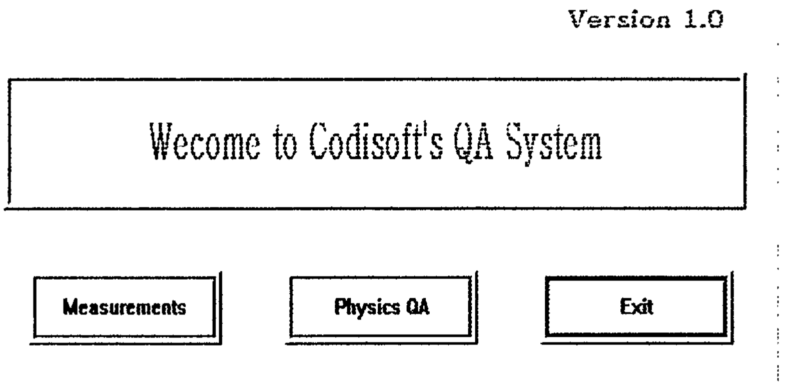


그림 3. 5. 16a User Interface의 Main Menu (80% 완성)

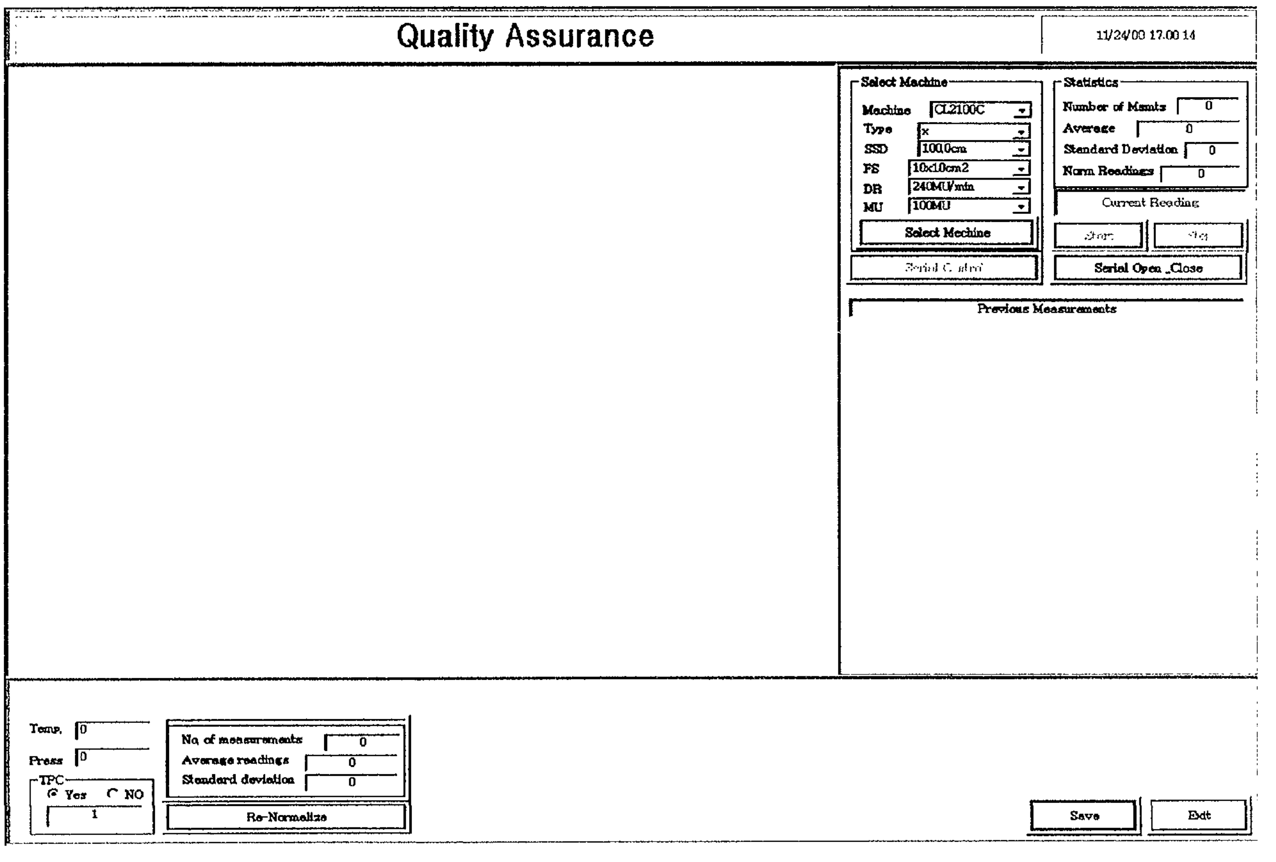


그림 3. 5. 16b User Interface (80% 완성)
Electrometer의 data 수집, processing tool, database

4. 정도관리용 dosimetric system의 사양확정

(가) 방사선 특성

No	item	사양	remark
1	stability	< 0.2%	표준 setup상의 reading 기준
2	linearity	< 0.5%	20 - 320MU (100MU기준)
3	Dose Rate Effect	< 0.5%	80 - 300MU/min (240MU/min 기준)
4	Stem Effect	< 0.2%	5cm*20cm, 20cm*5cm
5	Resolution	< 0.1pC	
6	Gain Switching	3 steps	
7	Communication	RS232	
8	leakage current	< 20fAmp	
9	zero drift	< 20fAmp	

(나) 기계적 특성

No	item	사양	remark
1	chamber의 mechanical clearance	< 0.5mm	
2	chamber의 weight	< 4Kg	
3	chamber dismension	30cm*30cm*12cm	
4	buildup plate	> 5cm	
5	backscattering medium	> 5cm	
6	chamber nominal volume	~1.0cc	
7	channel 수	최대 12개	

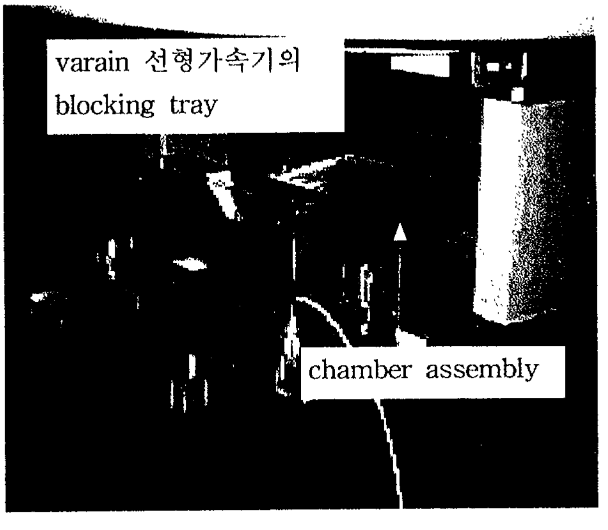
5. Dosimetric system A의 결과물

(가) Setup diagram

그림 3.5.17 참조

(나) 일일 정도관리 결과 (Varian 2100C: 6/10MV X-ray)

No	item	results	remark
1	stability	< 0.2%	20번 측정의 standard deviation
2	linearity	~1.0%	
3	Dose Rate Effect	< 0.5%	
4	Zero Drift	100fAmp	
5	Leakage current	100fAmp	



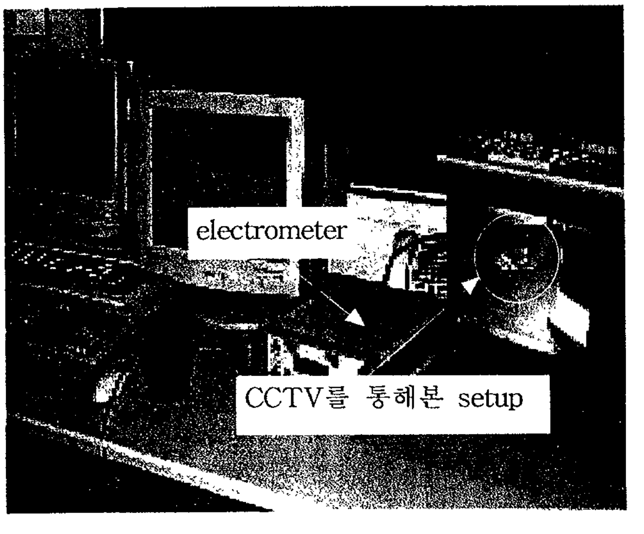


그림 3.5.17 Varian 선형가속기 CL2100C에 장착된 ionization chamber와 조정실에 위치한 electrometer (선형가속기의 일일 정도관리)

6. "Dosimetric system B" 의 결과물

(가) ionization chamber

① air-tight ionization chamber

② 9V battery를 이용한 330V generator의 high-voltage 이용

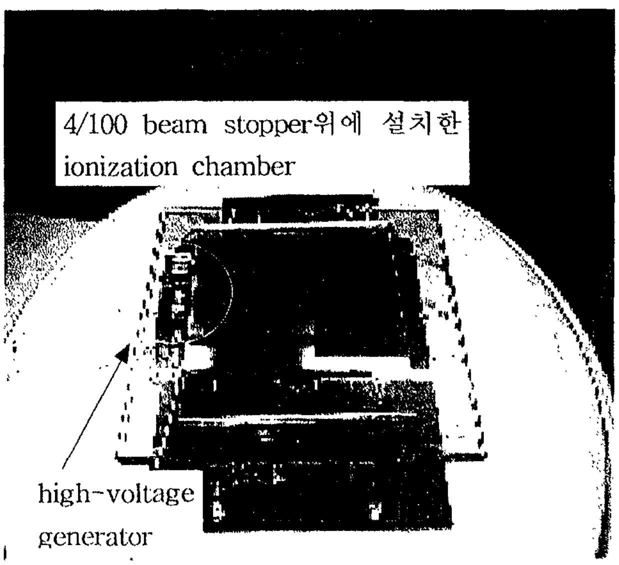
No	item	사양	remark
1	Main battery	9V	
2	Current Consumption	200mA	
3	Battery Life	2 hours	
4	Output (Ripple)	306V (+/-1%)	

표 high-voltage generator의 측정결과

(나) electrometer의 측정 결과

- stability (20회 실시): < 0.18% (air-tight chamber의 유용성 입증)
- leakage current: 100fA
- zero drift current: 100fA
- feedback capacitor (MK capacitor): 0.027uF
- battery life: 2.5 hours

(다) 문제점: battery의 life가 너무 적음 (다음의 rechargeable battery 이용)



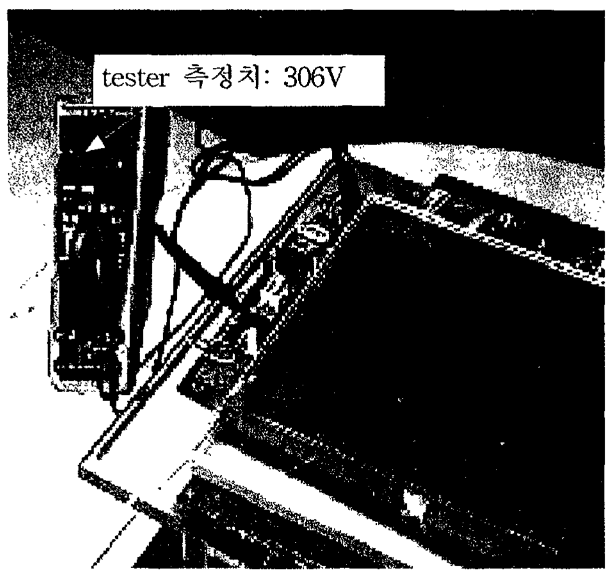


그림 3. 5. 18 Varian 선형가속기 4/100에 장착된 air-tight ionization chamber와 high-voltage generator와 조정실에 위치한 electrometer (선형가속기의 일일 정도관리)

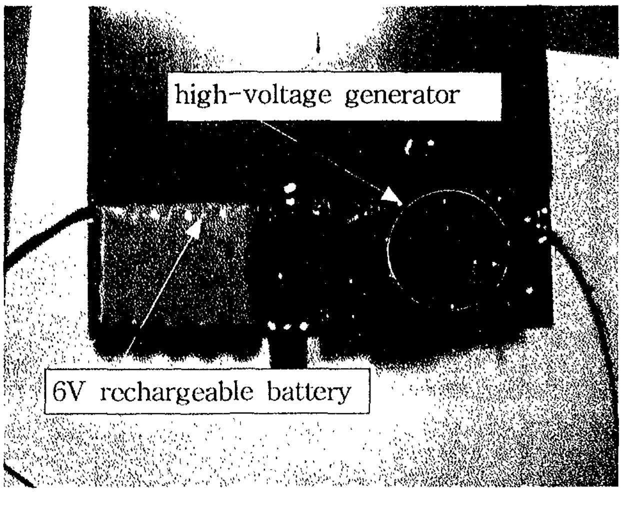
7. Dosimetric system C의 결과물

(가) ionization chamber
① air-tight ionization chamber
② 6V battery를 이용한 317V generator의 high-voltage 이용

No	item	사양	remark
1	Main battery	6V, rechargeable	
2	Current Consumption	30mA	
3	Battery Life	30 hours	
4	Output (Ripple)	174V (3V)	

표 high-voltage generator의 측정결과

(나) electrometer의 측정완료
- stability : <0.2%
- leakage current: 20fA
- zero drift current: 20fA
- feedback capacitor (MK capacitor): 0.027uF
- battery life: 30 hours (30 hour후 165 Volts)



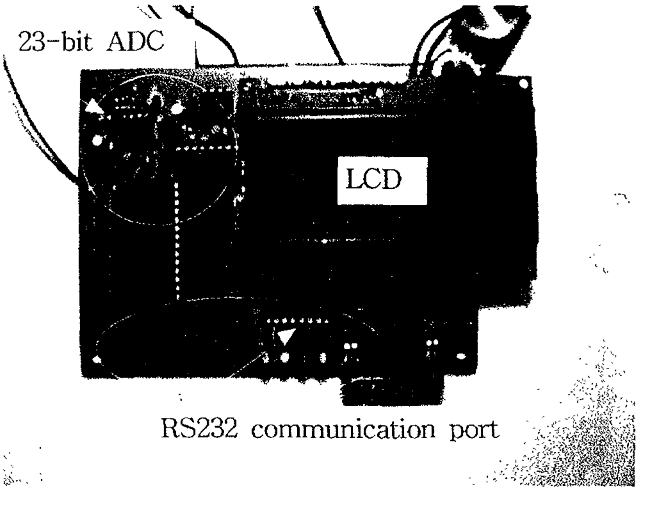


그림 170V high-voltage generator와 electrometer의 조립도

표 3. 5. 1 Ouput 측정 (CL2100C 10MV)

date	Machine	item	측정 및 측정조건 10MV, 10cm8*0cm, DR=400 SSD=100cm, 100MU 15min warmup	Temp Press TPC	avg	remark
10/13/2000 18:00	CL2100C	Output	0.720 ,0.652, 0.623, 0.618, 0.618, 0.618, 0.618, 0.618, 0.618, 0.618 0.618, 0.618, 0.613, 0.613, 0.613, 0.618, 0.618, 0.610, 0.618, 0.618	24°C 763mmHg TPC=1.003	0.618	0.620
10/24/2000 19:45	CL2100C	Output	0.705, 0.647, 0.623, 0.613, 0.613, 0.613, 0.608, 0.618, 0.608, 0.613, 0.613, 0.618, 0.618, 0.618, 0.613, 0.613, 0.613, 0.613, 0.613, 0.618	24°C 762mmHg TPC=1.003	0.615	0.618
10/26/2000 17:50	CL2100C	Ouptut	0.642, 0.623, 0.618, 0.613, 0.613, 0.613, 0.608, 0.613, 0.613, 0.613, 0.613, 0.618, 0.618, 0.613, 0.613, 0.613, 0.618, 0.613, 0.613, 0.613	23.5°C 760mmHg TPC=1.006	0.613	0.617
10/27/2000 17:45	CL2100C	Output	0.691, 0.632, 0.613, 0.608, 0.608, 0.608, 0.613, 0.613, 0.613, 0.603, 0.618, 0.618, 0.618, 0.613, 0.613, 0.618, 0.613, 0.613, 0.613, 0.613	24.5°C 768mmHg TPC=0.998	0.616	0.615
10/29/2000 15:30	CL2100C	Output	0.691, 0.621, 0.613, 0.608, 0.608, 0.608, 0.603, 0.603, 0.603, 0.608, 0.608, 0.608, 0.613, 0.608, 0.613, 0.613, 0.613, 0.613, 0.613, 0.613	23.0°C 761mmHg TPC=1.003	0.610	0.612
10/30/2000 17:00	CL2100C	Output	0.686, 0.642, 0.623, 0.618, 0.618 0.618, 0.608, 0.613, 0.613, 0.608, 0.613, 0.613, 0.608, 0.618. 0.613, 0.613, 0.613, 0.613, 0.613, 0.613	22.0°C 765.5mmHg TPC=0.993	0.613	0.608

서울대학교 치료방사선과에서 Dosimetric System의 임상적용시 문제점을 파악하기위해서 2주일간 측정한 data중 일부임.

8. lab prototype의 방사선 특성 조사

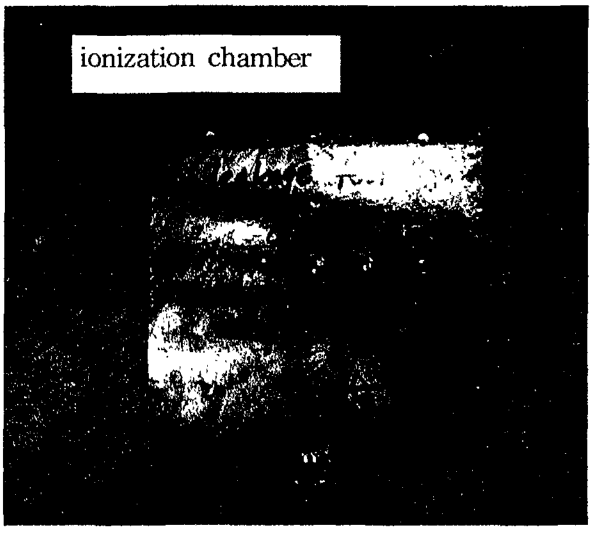
(1) electrometer test용 ionization chamber (아래 그림 참조)

(2) lab prototype의 electrometer의 제작

(3) 기계적 정확도 측정

① Mechanical Accuracy: < 0.5mm

② Radiation Accuracy: < 0.2%



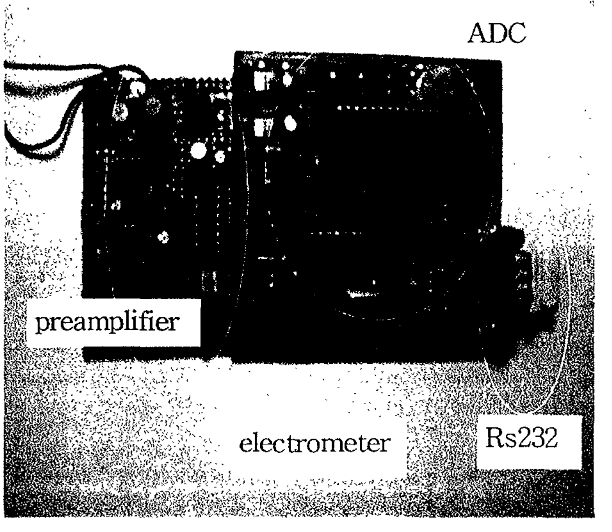
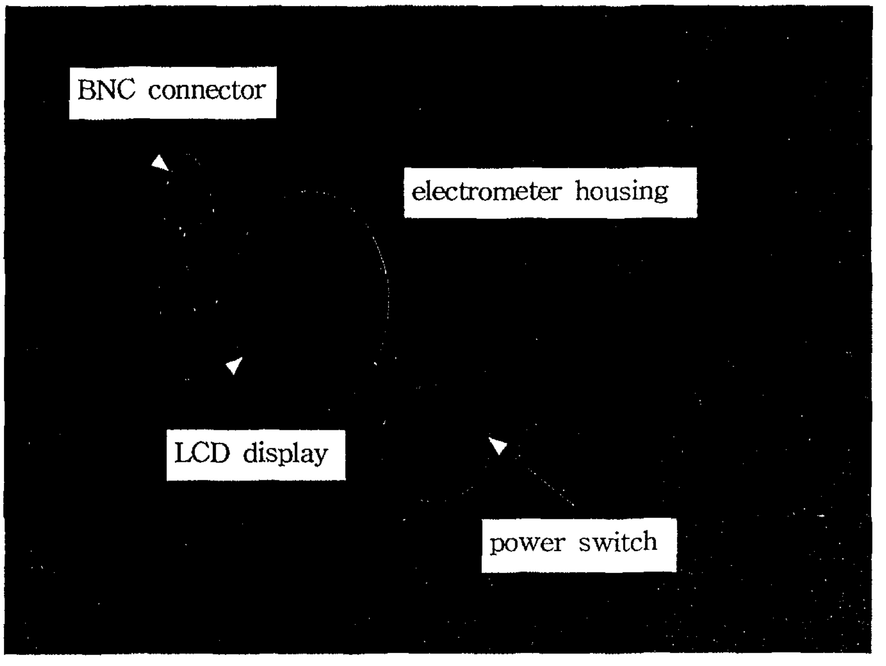


그림 lab prototype의 ionization chamber와 electrometer의 구성

8. engineering (또는 pilot) prototype의 방사선 특성 조사

8.1 channel electrometer with LCD)

8.1.1 제작된 electrometer

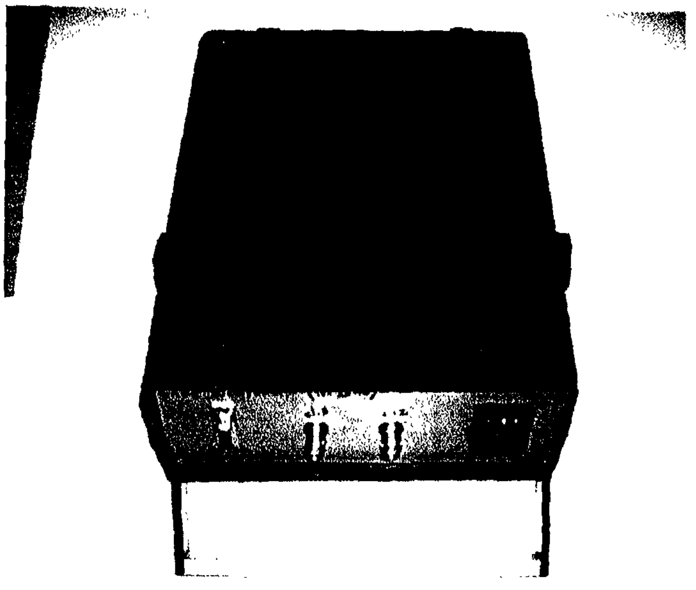


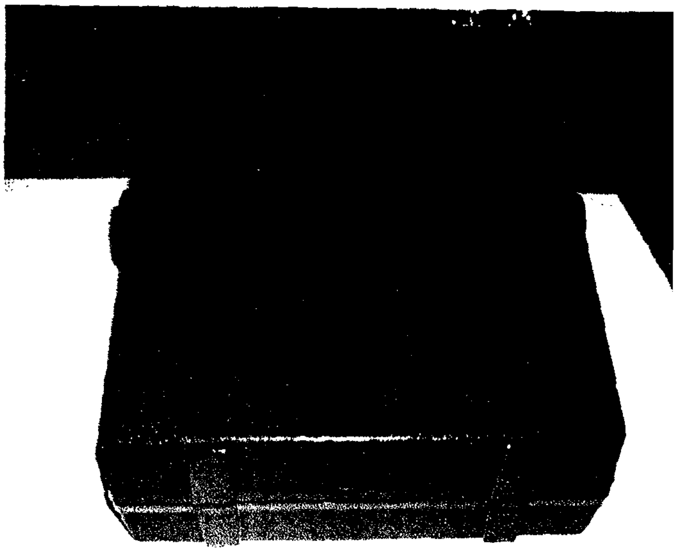
8.1.2 사양 및 측정 data

No	사양	측정값	비고
1	channel number	2	
2	display value	voltage	coulomb=value/0.027pF
3	display digit	3 1/2	
4	power	110/220 free voltage	
5	ADC	16 bits	
6	amplifier	ACF2101	
7	feedback capacitor	2700nF polyester capacitor	
8	zero drift/leakage current	50fAmp	
9	gain switch	2	

8.2 Diode용 electrometer

8.2.1 제작된 electrometer



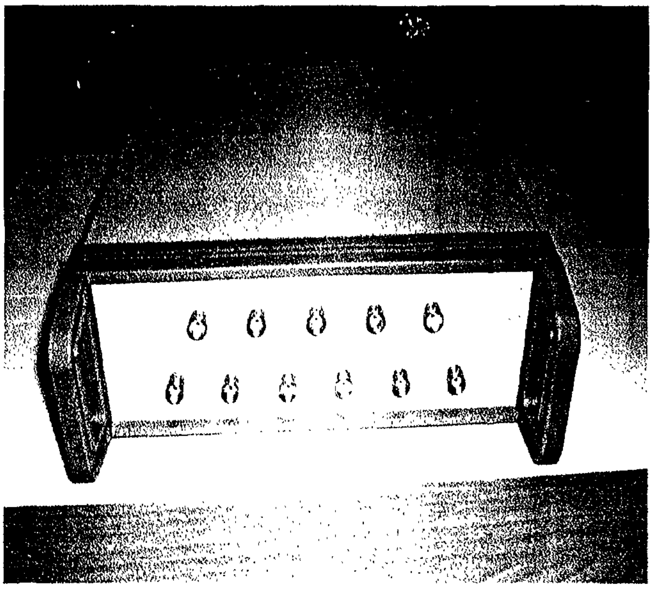
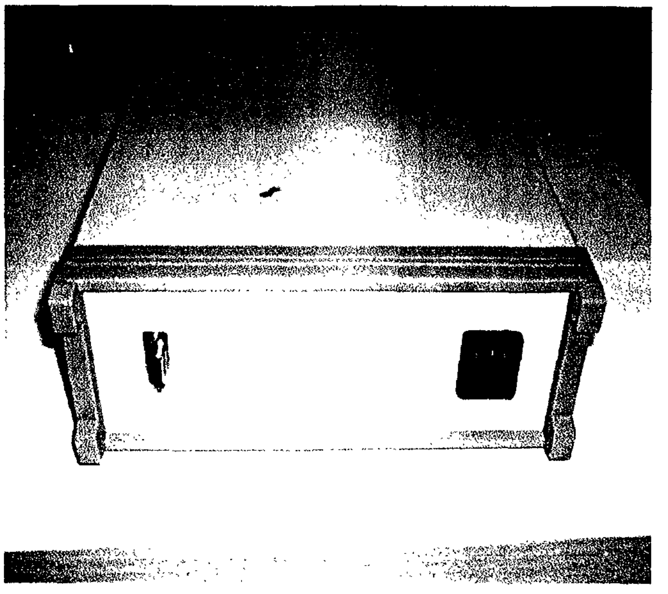


8.2.2. 측정 사양

No	사양	측정값	비고
1	channel number	2	
2	display value	voltage	coulomb=value/0.027pF
3	computer interface	RS-232	
4	power	110/220 free voltage	
5	ADC	16 bits	
6	amplifier	ACF2101	
7	feedback capacitor	2700nF polyester capacitor	
8	zero drift/leakage current	30fAmp	
9	gain switch	3	

8.3 Multi-channel (8-channel) electrometer

8.3.1 제작된 multi-channel electrometer

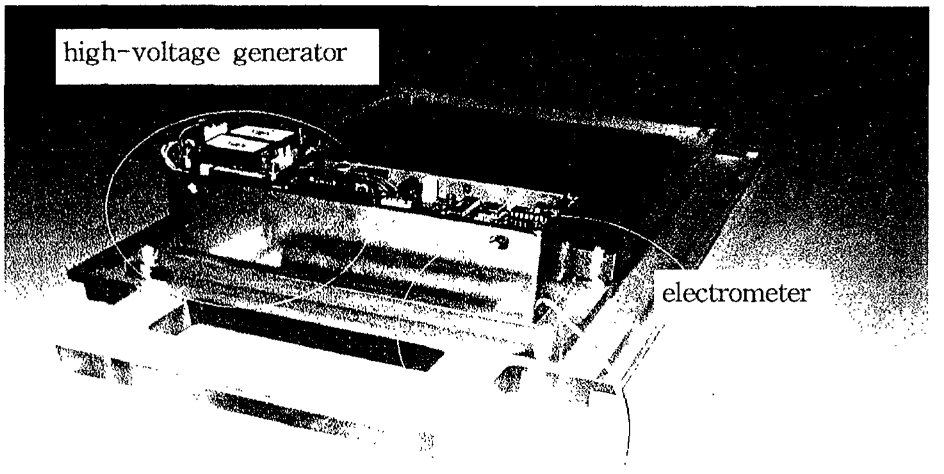



8.3.2 사양 및 측정 data

No	사양	측정값	비고
1	channel number	8	
2	display value	voltage	coulomb=value/0.027pF
3	computer interface	RS-232	
4	power	110/220 free voltage	
5	ADC	16 bits	
6	amplifier	ACF2101	
7	feedback capacitor	2700nF polyester capacitor	
8	zero drift/leakage current	30fAmp	
9	gain switch	3	

8.4 Computer-based dosimetric system

8.4.1 제작된 dosimetric system (통합형 ionization chamber와 electrometer)



8.4.2 제작된 dosimetric system (통합형 ionization chamber와 electrometer)

No	사양	측정값	비고
1	channel number	1	
2	display value	voltage	coulomb=value/0.027pF
3	computer interface	RS-232	
4	power	110/220 free voltage	
5	ADC	16 bits	
6	amplifier	ACF2101	
7	feedback capacitor	2700nF polyester capacitor	
8	zero drift/leakage current	30fAmp	
9	gain switch	3	

9. 본 system의 확장성 (본 project 연구의 부산물)

(1) stacked ionization chamber

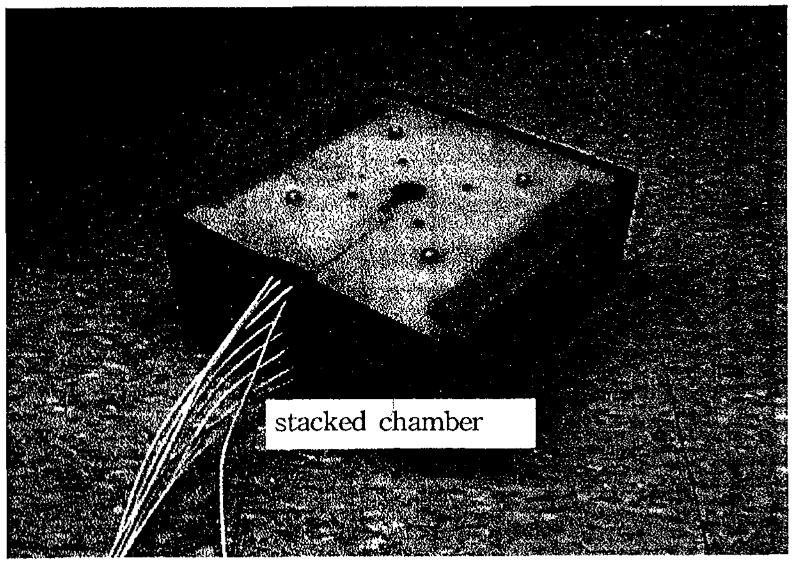
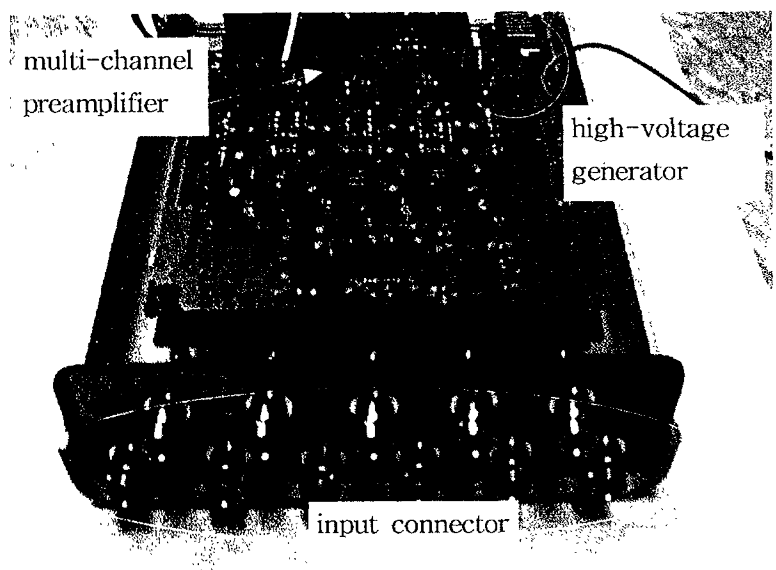


그림 stacked channel ionization chamber의 구현

(2) electrometer

- 8 channel electrometer의 구현



제 4 장 연구개발 목표 달성도 및 대외 기여도

1 절 목표 달성도

가. ionization chamber 관련

No	항목	목표사양	달성	비고
1	ion chamber type	parallel plate	parallel plate	
2	sensitive volume	1.0cc	1.0cc, 0.1cc	
3	medium	acrylic plate	acrylic plate	ρ_e = 1.014 +/- 0.001
4	buidlup	5cm acrylic plate	5cm buildup	max 20MV X-ray
5	backscattering	5cm acrylic plate	5cm acrylic plate	
6	electrode material	carbon	Ag/Cu/Pb	저가의 chamber
7	gas의 형태	air ventilated type	air ventilated/tight type	dry air 이용
8	high-voltage	단일의 300V battery	6V battety를 이용한 300V generator 구현	
9	leakage current	< 10fAmp	1 - 5fAmp	
10	RF interference	negligible	negligible	고가의 계측기 필요
11	Shielding	negligible	negligible	고가의 계측기 필요
12	Mechanical Accuracy	< 1mm	< 0.2mm	
13	cable	RG-39 cable	RG-39 cable	

나. electrometer

No	항목	목표사양	System A	System B	System C
1	channel 수	2	2	2	8
2	computer interface	없슴	없슴	RS-232	RS-232
3	power	100/200 V	100/200 V	100/200 V	6V battery
4	amplifier용 IC	OPA128	OPA128	ACF2101	ACF2101
5	gain switch	2 단계	없슴	2 단계	3 단계
6	ADC	16 bits	12 bits	16 bits	18 bits
7	Zero drift Current	< 100fAmp	< 200fAmp	< 100fAmp	< 20fAmp
8	Leakage Current	< 100fAmp	< 200fAmp	< 100fAmp	< 40fAmp
9	Microprocessor	없슴	8-bit processor	EPROM	EPROM
10	Display	LCD	LCD	LCD	computer interface
11	high voltage (> 300V)	ion chamber 에 장착	없슴	없슴	317 +/- 2V
12	housing	Al housing	Al housing	Al housing	AL housing

다. 성능의 우수성

No	item	외국의 제품	개발된 제품	비고
1	가격	20,000-30,00 US$	4,000US$	100% 국산화
2	ionization chamber의 견고성	fragile (carbon)	PCB이용한 단단한 구조	
3	cable	고가의 tri-axial cable (2-3년에 한번씩 교체)	저가의 bi-axial cable 이용	
4	interface	LCD	(1) LCD (2) RS-232 interface	
5	ionization chamber의 high voltage generator	high-voltage generator (300V) 또는 300V의 battery 이용	(1) rechargeable battery 이용 (2) high voltage generator제작	
6	storage/carry	special harness 필요	no special harness	
7	muti-channel로의 확장성	없음	64 channel 까지 확장성	
8	liquid detector로의 확장성	없음	liquid detector 제작이 용이	
9	RF-based dosimetric system 설계	없음	RF-based dosimetric system의 핵심 기술 축적	

2절 관련분야의 기술발전의 기여도

No	item	응용분야	기여도
1	low-noise amplifier	(1) 진단 방사선과 (2) 핵의하과 (3) 원자력 발전소 방사선 계측	핵심 기술 보유
2	ADC	(1) 소신호 응용 (2) chromatography	핵심 기술 보유
3	RS232 communication (24 bit)	(1) biomedical system (2) control system	핵심 기술 보유
4	의학용 방사선 등가 물질 개발	(1) 치료방사선 (2) 핵의하과 (3) Gamma Knife center	기술 보유

제 5 장 연구개발결과의 활용계획

1 절 타연구에의 응용

1. Radiation Survey Meter에의 기술 적용

가. GM counter (GMC) /Proportional Counter (PC)

(1) GM tube의 신호처리 영역

(2) Proportional Counter의 신호처리 영역

나. Liquid Detector (high resolution: <1mm)개발

(1) 치료방사선응용

① Dynamic Wedge의 radiation field scanning

② Multi-Leaf Collimiator (MLC)의 radiation field scanning

③ 선형가속기의 연례 정도관리를 위한 Water Scanner의 detector

④ 선형가속기의 월례 정도관리를 위한 flatness/symmetry 측정용 detector

(2) 저준위/저가의 방사선 Monitoring System

다. 대형 병원등의 방사선 monitoring system

(1) 진단방사선과 (혈관조형술등의)의 방사선 monitoring system

(2) 핵의학과의 방사선 monitoring system

① high-energy (2MeV 까지) 의 electron beam 측정용

② high-energy (2MV 까지) 의 photon beam 측정용

2. Radiation Monitoring System에의 응용

가. 환경방사능의 monitoring system

(1) 쓰레기 하치장 (예를 들면, 난지도)의 저준위 방사선 측정용

(2) 원자력 사고에 대비한 방사선 측정용

① 냉전시대의 핵실험

② 국내의 원자력 발전소의 방사선영향 평가

③ 핵전쟁시 아군의 보호를 위한 방사선영향 평가

④ 사고시 조기경보체재 system 구축

나. 환경방사능의 monitoring system의 구성

(Internet-based RF radiation monitoring system)

(제안된 system의 block diagram: 다음 그림 참조)

(1) photon detector, electron detector, neutron detector

(2) multichannel electrometer

① dosemeter (3 step gain selection)

② doserate meter (3 step gain selection)

③ high-voltage generator (300, 1000 Volts)

(3) Radio Frequency (RF) system

① Frequency Synthesizer에의한 주파수 발생장치

② 가변의 RF power의 automatic control (power saving)

(4) Receiver 및 PC interface

① 128개의 RF system control

③ internet interface

(5) Central Monitoring System

① Internet-based data processing

② realtime data processing, automatic warning system

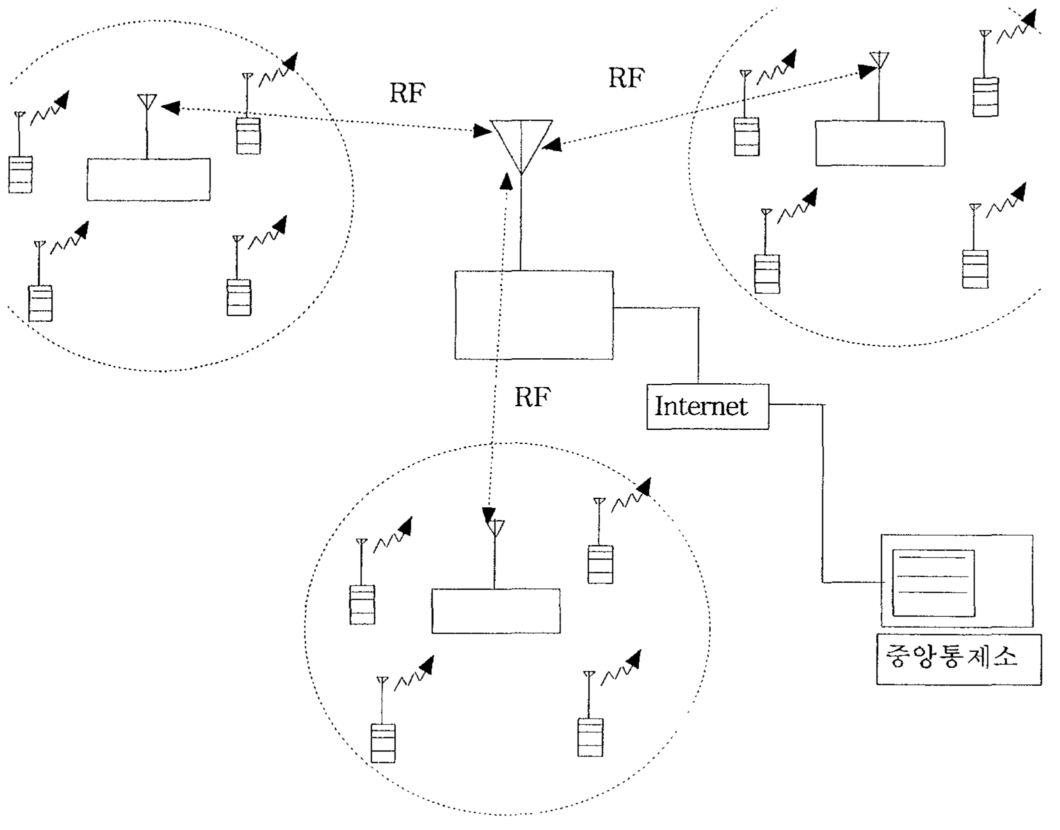


그림 Internet/RF-based Radiation Monitoring System

3. 치료방사선의 근접치료용 방사선원의 정도관리용 dosemeter (chamber 와 electrometer)

가. Well type의 고압력 (20 psi) ionization chamber 개발 (아래 그림 참조)

(1) Ir-192 방사선원 (High-dose rate기기 및 비파괴검사용의 방사선원)

(2) Cs-127 방사선원 (자궁암 치료에 이용되는 방사선원)

나. Well type ionization chamber의 electrometer

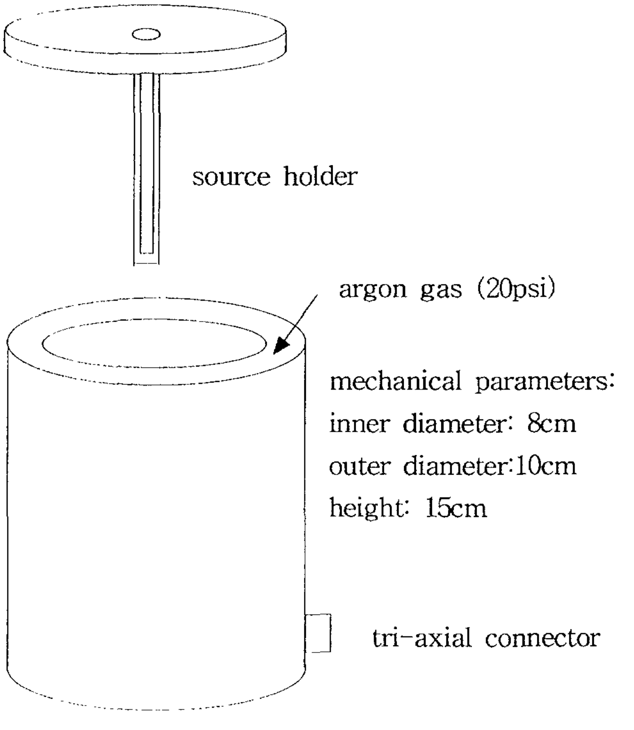


그림 Well type (4 π geometry) ionization chamber

2 절 기업화 추진방안

- 서울대학교 치료방사선과에서 임상실험 완료
- 단국대학교 치료방사선과에서 임상실험 완료
- (주) 코디소프트에서 상품화 하였으며, 본사에서 제작, 영업계획
- 중국의 Nu Alpine사 (Linac, CT, MRI 제작 venture 기업)과 기술 이전 협의중

제 6 장 참고문헌

1. J. G. Holt, A. Buffa, D.Perry, I. Ma, and J. McDonald
"Absorbed Dose Measurements Using Parallel Plate Polystyrene Ionization Chambers in Polystyreen Phantom"
Int. J. Radiation Oncology Biol. Phys. Vol. 5 pp.2031 - 2038
2. Technical mannual of PTW
   - Ionization Chamber Type 23342
   - Ionization Chamber Type 23322
   - Ionization Chamber Type 23323
   - Ionization Chamber Type 31003
   - Ionization Chamber Type 30001
   - Ionization Chamber Type 30004
   - Ionization Chamber Type 23343
   - Ionization Chamber Type 77334
   - Ionization Chamber Type 233612
   - Ionization Chamber Type 32002
   - PTW/Marcus Electron Beam Chamber
   - Holt/Parallel Plate Chamber
3. BurrBrown's IC Manual
   - pp. 2.53 - pp. 2.61 OPA 128 Low Noise Amplifier
   - pp. 7.5 - pp. 7.16 ACF 2101 Low Noise, Dual Switched Integrator
   - pp.1 - pp.35 ADS1210/ADS1211 24-bit ADC
4. Analog Device IC Manual
   - Rev. A. AD780 High Precision Reference
5. Operation and Instruction Mannual, Victoreen,
Ion Chamber Survey Meter Model 450
6. Operation and Instruction Mannual, Keithley Electrometer Model 35614
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7. Instruction Manual for Dose-doserate Meter Type 2620,
NE Technology, Limited
8. Operation and Instruction Mannual, Nuclear Associates, Model 415
9. Instruction Mannual, Xetrex, Digital Dosemeter, Model 415A/B
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11. Johns and Cunningham, Therapeutical Physics
12. Operation and Instruction Mannual, Varian Linear Accelerator, CL2100C

13. Operation and Instruction Mannual, Varian Linear Accelerator, 4/100
14. Operation and Instruction Mannual, Varian Linear Accelerator, 6/100
15. The Essential Physics of Medical Imaging
by J.T. Bushberg, J.A. Seibert, and E.M. Leidholdt
16. Radaition Therapy Planning, G.C. Bentel

부 록

1. An Example of the Quality Assurance Program for Ionization Chambers
2. An Example of the Quality Assurance Program for Electrometers
3. Instruction Manual for 0.6cc Ionization Chamber
4. Ionization Chamber Type 233612
5. Ionization Chamber Type 77334
6. Ionization Chamber Type 34001
7. Ionization Chamber Type 23343
8. Ionization Chamber Type 30001
9. Ionization Chamber Type 31003
10. Ionization Chamber Type 31002
11. Ionization Chamber Type 23323
12. Ionization Chamber Type 23322
13. Ionization Chamber Type 23344
14. Ionization Chamber Type 23342
15. Operational Manual Patient Dose Verification System (Model TN-RD-50)
16. Instruction Maunal Solid Water Phantom Type 29672
17. Precision Dosimetry System Electrometer
18. Re-entrant Chamber for HSR & LDR
19. Isorad Detector
20. Rainbow System
21. Therapy Beam Monitor
22. Instruction Manual for Dose/Dose-rate Meter Type 2620

Evaluation of the Performance of Ionization Chambers

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Department of Radiation Oncology
College of Medicine
Korea University
Seoul, KOREA

CSK

Specific Aims

- An ionization chamber is major equipment for the measurement of radiation and its performance strongly effect on accuracy and precision of output calibration and/or radiation dosimetry.
- In this study, many factors which affect the performance of ionization chambers are listed and performance tests are done.
- This approach may assist users in maintaining their ionization chambers and in making accurate dosimetric measurements.

Materials & Methods

- List of tests for Ion chambers
  - Leakage
  - Stem effect
  - Radiation equilibration time
  - Repeatability
  - Linearity
  - Atmospheric communication
  - Orientation dependency
- X- & gamma-ray sources
  - 0.9 mCi Sr-60 check device (type 23261)
  - Clinac (600C, Varian)
- Electrometer & Ion chambers
  - IQ-4 (PTW)
  - Rigid stem chamber (M23332)
  - Cylindrical chamber (M233641)

Materials & Methods

- Leakage
  - Change of reading within a couple of minutes after irradiation
  - cylindrical chamber with 300 volt polarizing voltage
  - 500 cGy, 250 MU/min
- Radiation equilibration time
  - Time required for reaching threshold of charged state after power-on
  - Related to the warm-up time of the electrometer used in the measurement

Materials & Methods

- Stem effect
  - Effect of the amount of guarding and the quality of the insulators
  - Irradiation of the chamber with elongated field with the length of the stem kept constant
  - 300 MU
  - 5 cm x (5 - 30) cm elongated field
- Orientation dependency
  - Check of the deviation of the central electrode and the high Z impurities in the dag coating in a particular direction of the chamber
  - Same amount of radiation with different chamber orientation alon with the chamber axis
  - 500 MU, 300 volt bias voltage

Materials & Methods

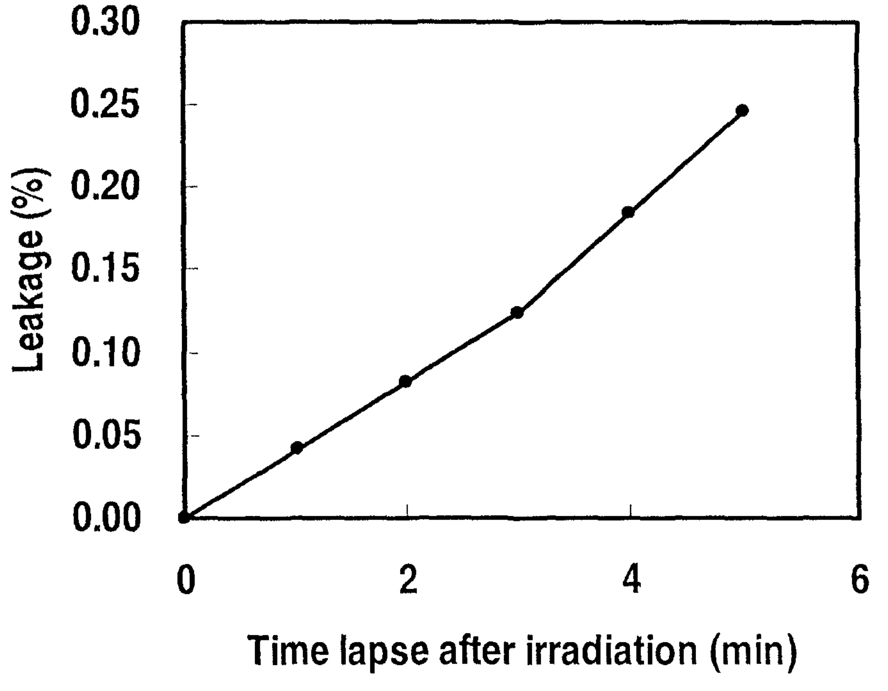
- Repeatability
  - Repeatability of the chamber response
  - Checker device
  - 300 volt bias voltage, 5 minute 10 exposure
- Linearity
  - Multiple exposures of an ion chamber, where n exposures should yield n times the initial signal
  - Checker device & LINAC
  - Rigid step chamber & cylindrical chamber
  - Up to 500 MU and 10 minutes exposure

Materials & Methods

- Atmospheric communication
  - By artificially altering the temperature or pressure, or by simply making accurate measurements on two different days when the temperature pressure correction has changed by 1% or more
  - Change of the measuring temperature from 24 to 30 ^{0}C (constant pressure)

Results

(Leakage)



- Ionization chamber leakage after radiation was 0.2 and 0.5% at 2 and 5 minutes, respectively.
- Chamber leakage was increased with the elapse time after radiation.

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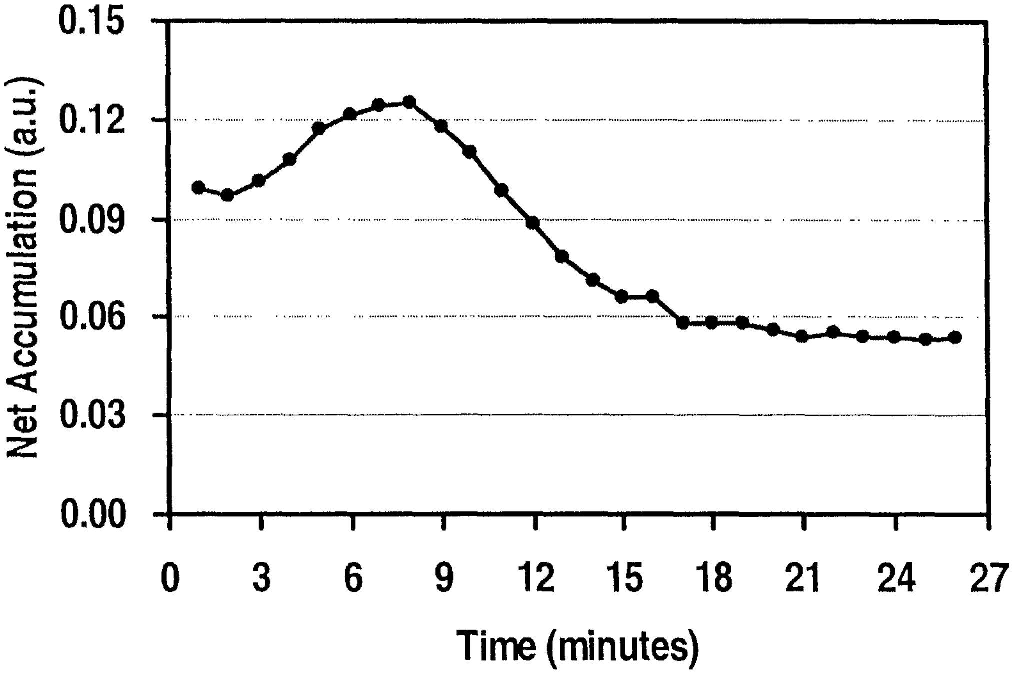
Results

(Radiation equilibration time)



- After the polarization voltage was applied to the ionization chamber through the electrometer, the lamp was alight for about 11 minutes at 22.9 ^{0}C
- After 15 minutes, the ionization chamber was performed well with its repeatability greater than 99.7%.

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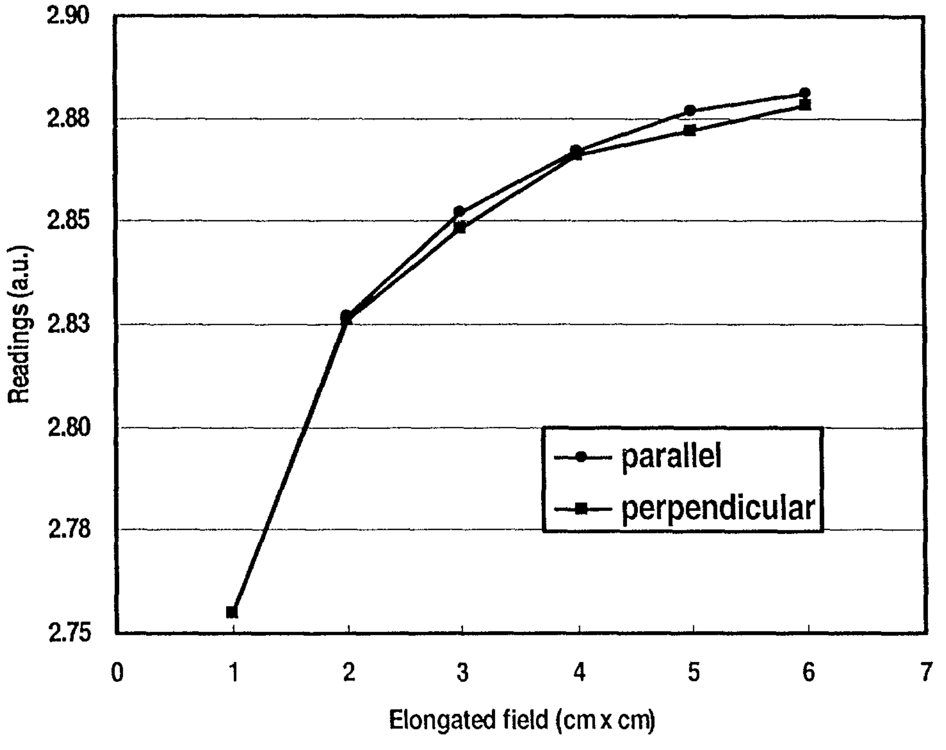
Results
(Stem effect)



- Measurement was performed for two different field orientations, parallel and perpendicular to the chamber axis.
- For the clinically-interested field ranges, the difference was minimal, less than 0.2%.

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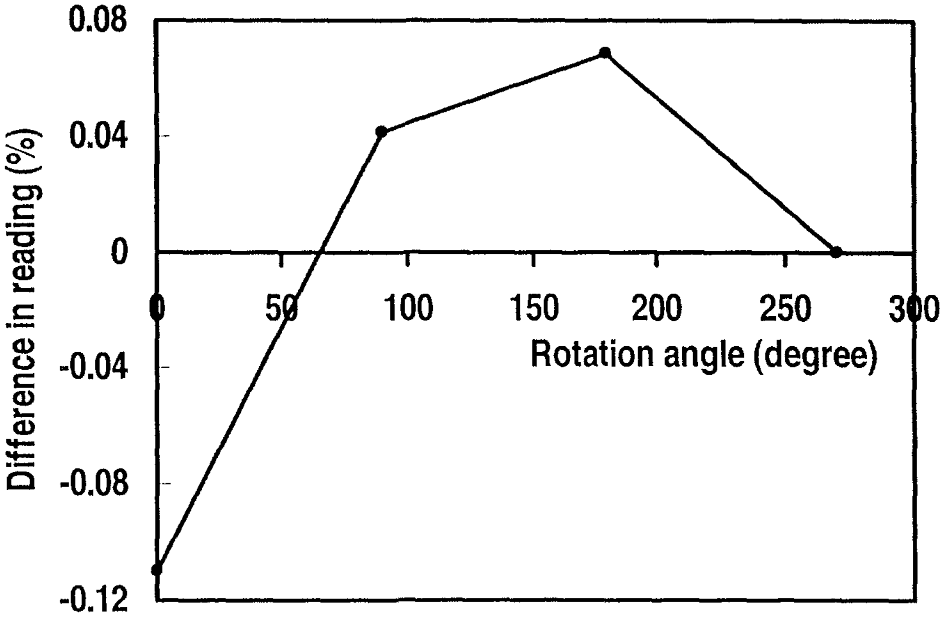
Results
(Orientation dependency)



- Chamber response varies within 0.15% for different chamber orientation
- Indirect evidence of the central electrode at the right position and no high Z impurities in the dag coating

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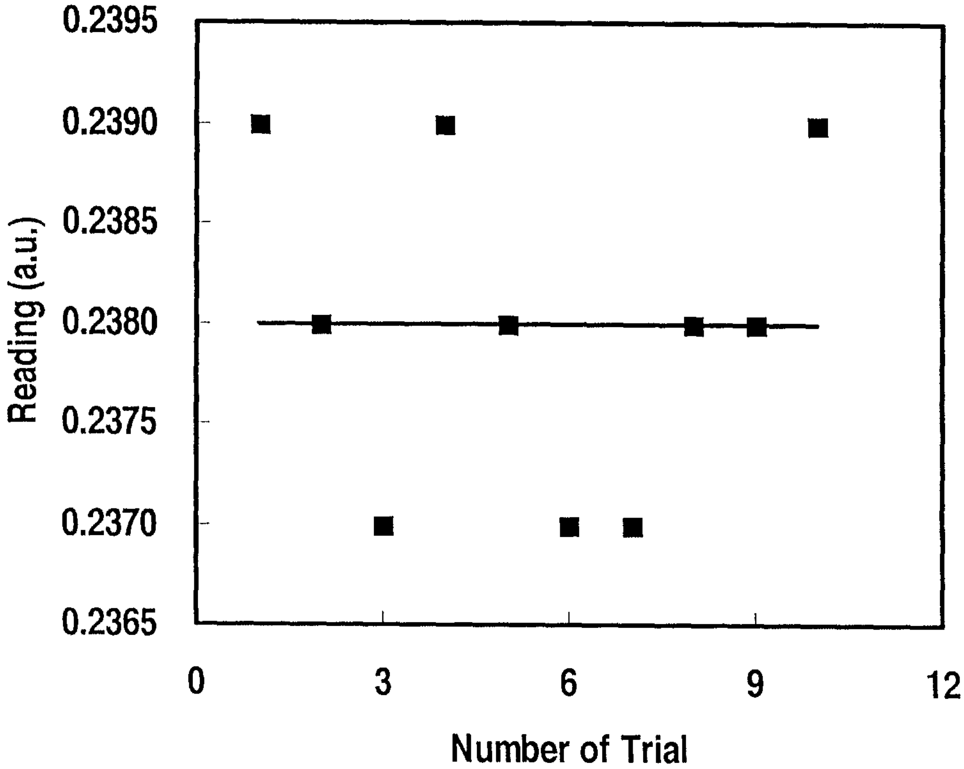
Results

(Repeatability)



- The chamber reading was same within 0.08 % for ten trials.

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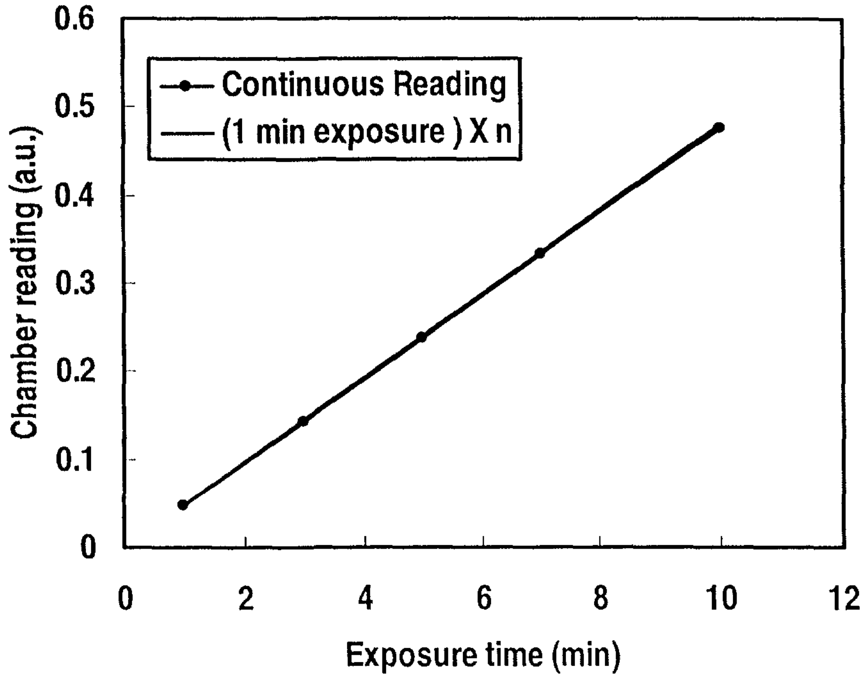
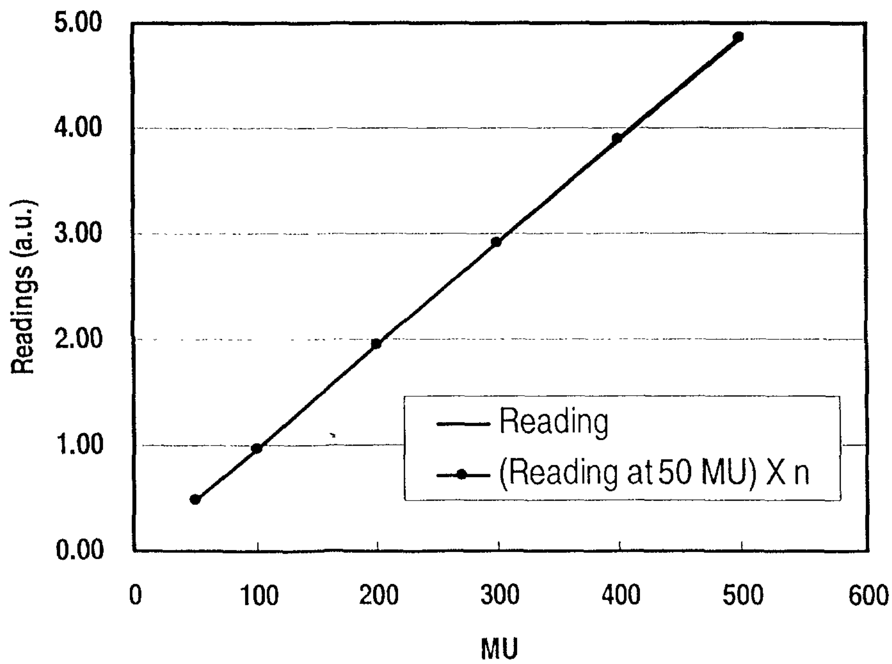
Results
(Linearity)





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Results

(Atmospheric communication)

	Conditions 1	Conditions 2
Temperature (^{0}C)	24.0	30.2
Pressure (mmHg)	766.0	766.0
$C_{T,P}$	1.006	0.993
Reading	0.960	0.955
Corrected Reading	0.966	0.948

- The effect of the ambient conditions, specially temperature change, can affect the sensitivity of an ion chamber.
- With the consideration of the variation of the temperature, temperature-pressure correction > 1%, the corrected reading was followed the temperature change.

CSK

Conclusions

- Many factors which affect the performance of ionization chambers are listed.
- Test methods are shown and performance tests of ionization chambers were performed.
- This approach may assist users in maintaining their ionization chambers and in making accurate dosimetric measurements.

An Example of the Quality Assurance Program for Electrometers

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CSK

Specific Aims

- An electrometer along with an ionization chamber is major equipment for the measurement of radiation and its performance strongly effect on accuracy and precision of output calibration and radiation dosimetry.
- To show a list of quality assurance tests to keep the performance of an electrometer
- To do performance tests of an electrometer
- To assist users in maintaining their instrumentation and in making accurate dosimetric measurements

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Materials & Methods

- List of Tests for Electrometer
  - Recommendation of the manufacturer
  - Proper voltage levels
  - Warm-up time and equalization time after high voltage
  - Leakage
  - Zero drift from the background current
  - Long-term stability
  - Linearity
  - Effect of ambient conditions
- Gamma-ray source
  - Sr-60
  - Check device (Type 23261)
- Electrometer & Ion chamber
  - IQ-4 (PTW)
  - Rigid stem chamber (M23332, PTW)

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Materials & Methods

- Proper voltage levels
  - Critical for the battery-operated electrometer
  - Bias voltage level affects on the collection efficiency.
  - Voltage levels for all bias
  - Comparison of the measured to the nominal voltages
- Warm-up time and equalization time after high voltage
  - Time required for reaching threshold of charged state after power-on
  - The time required for leakage equilibrium after switching polarity

Materials & Methods

- Pre-signal Leakage
  - Accumulation of signal from a zero condition
  - Sixty minutes after the power switch is on, thermal equilibrium, zero drift of the electrometer at the stable condition without any radiation was checked with a capacitor of 1 nF.
- Post-signal Leakage
  - The ability of the feedback capacitor to hold charge
  - Zero drift of the electrometer at the stable condition with 10 min exposure to check device

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Materials & Methods

- Long-term stability
  - Over three month periods
  - Conditions of various temperature and pressure
  - Comparison of the temperature-pressure corrected reading after two minutes exposure in check device
- Effect of ambient conditions
  - Zero drift of the electrometer over the temperature range, 17 - 34^0
  - The measurement was performed at the same day to keep the pressure constant.

Materials & Methods

- Linearity
  - Multiple exposures of an ion chamber, where n exposures should yield n times the initial signal
  - Checked for full scale range of the electrometer reading (0.000 - 9.999)

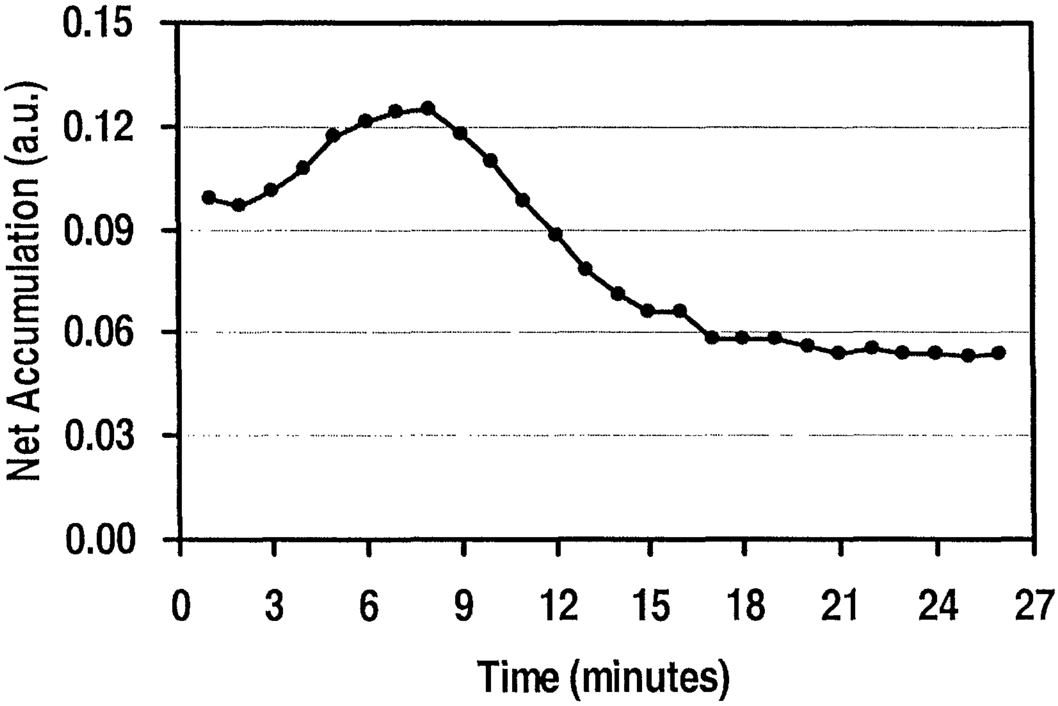
Results

(Proper voltage levels)

Polarizing Voltage (Nominal , volt)	Measured Value (volt)	Difference (%)
500	471	- 5.8
300	292.3	2.6

Results

(Warm-up time and equalization time after high voltage)



- After the IQ 4 is switched on, the lamp was alight for about 11 minutes at 22.9^{0}C.
- Measured equalization time after the polarizing voltage change from 500 to 300 volt and vice versa was less than 20 s.

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Results

(Pre-signal leakage)

- Before the adjustment

Time (minute)	1	2	3	4	5	6	7	10
Reading (scale unit)	0.000	0.001	0.002	0.003	0.005	0.006	0.006	0.009

- After the adjustment of the offset current

Time (minute)	1	...	5	...	10	...	15
Reading (scale unit)	0.000	...	0.000	...	0.001	...	0.002

- The scale unit 0.001 per minute corresponds to a leakage current of about 2×10^{-14} A for a capacitor of 1 nF.
- The display should be between - 0.002 and + 0.002 and should not changed by more than 0.001 per minute.

Results

(Post-signal leakage)

Time (minute)	0.5	1	2	3	...	5
Reading (scale unit)	0.000	0.000	0.000	0.000	...	0.000

- No drift of the reading was found within 0.001 after 5 minutes with the exposure of 10 min exposure to check device.

Results

(Long-term stability)

	Date of Measurement		
	5 / 27 / 99	6 / 30 / 99	8 / 28 / 99
Temperature (^{0}C)	25.0	23.5	26.0
Pressure (mmHg)	766.0	756.5	759.5
$C_{T,P}$	1.009	1.017	1.021
Reading	0.951	0.939	0.943
Corrected Reading	0.960	0.955	0.963

- Less than 0.7% variation in reading was found over three month periods.
- With the consideration of the variation of the temperature and pressure, the reading was measured within 0.5% in the same measurement conditions.

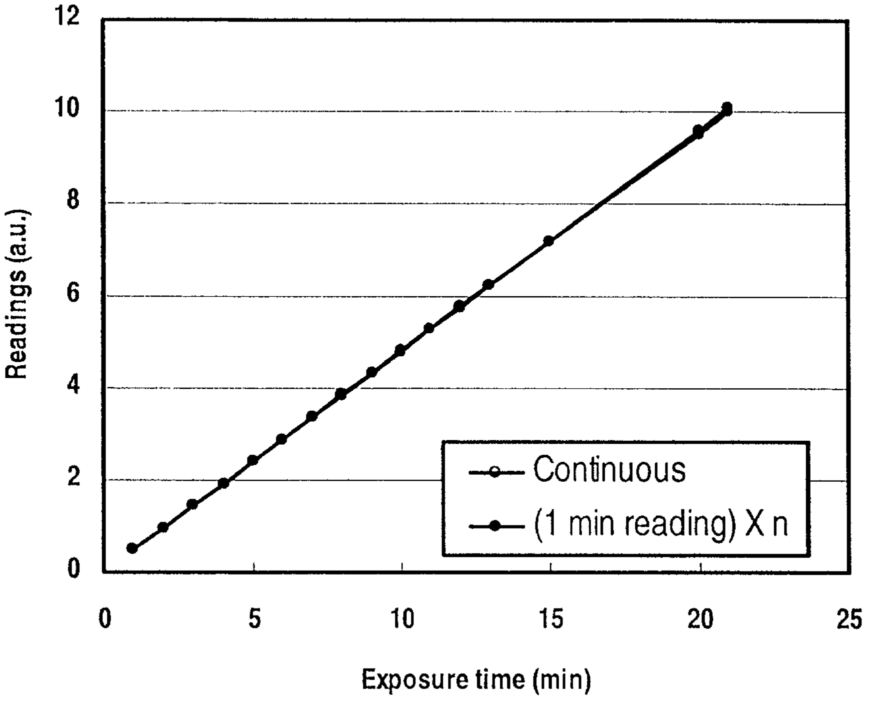
Results

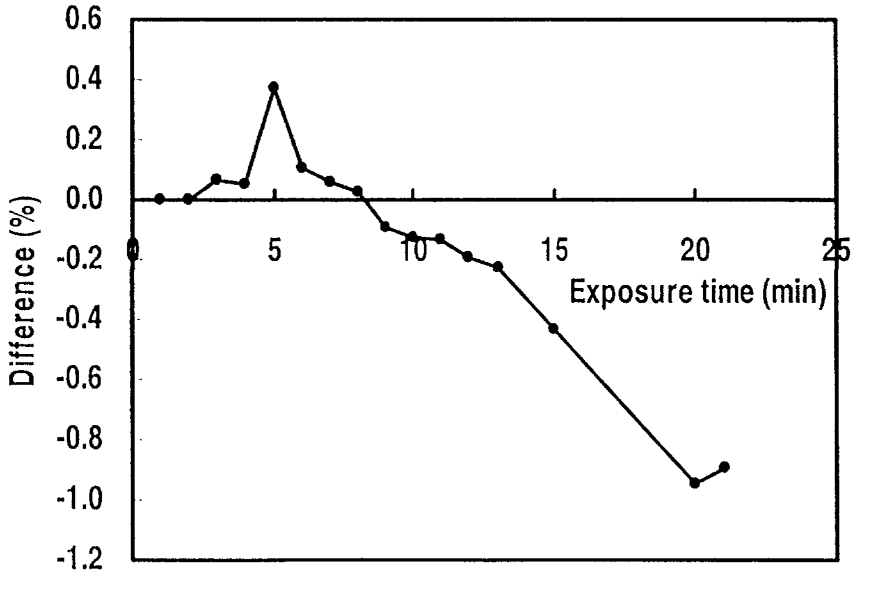
(Effect of ambient conditions)

Temperature (^0C)	17	24	34
Drift in 10 minutes	0.009	0.008	0.008

- The effect of the ambient conditions, specially temperature change, can affect the zero drift of the electrometer.
- In the measurement, the effect of the measuring temperature on the zero drift can be ignored in the range of 17 - 34 ^0C.

Results
(Linearity)





CSK

Conclusions

- Quality assurance tests for an electrometer are listed.
- Test methods are shown and performance tests of an electrometer were done.
- Periodic maintenance check of the electrometer is required for making accurate dosimetric measurements.

INSTRUCTION MANUAL

for

0.6cc IONISATION CHAMBER (GUARD STEM) TYPE 2571

This Manual was prepared for use with units with Serial Numbers between 2151 - 2250.

NE TECHNOLOGY LIMITED
Bath Road, Beenham, Reading
Berkshire RG7 5PR England

Tel Reading (0734) 712121
Telex 848475
Fax 0734 712835

CONTENTS

3. SPECIFICATION

3.1 PHYSICAL CHARACTERISTICS

3.1.1 Configuration

Outer Electrode:	Cylindrical thimble
Inner Electrode:	Cylindrical rod concentric with thimble

3.1.2 Active Dimensions

Sensitive Volume:	0.69 cm^3
Length of Volume:	24.1 mm
Outer Electrode, inner diameter:	6.3 mm
Inner Electrode, outer diameter:	1.0 mm
Length of Inner Electrode	20.6mm
Thimble Wall Thickness:	0.36 mm
Protective/build-up cap wall thickness:	3.87 mm

3.1.3 Exterior Dimensions

Thimble Outside Diameter:	6.99 ±0.04 mm
Stem Outside Diameter	8.62 ±0.04 mm
Protective/build-up cap outside diameter	15.14 mm

3.1.4 Materials

Outer Electrode:	Graphite 99.99% pure
Inner Electrode:	Aluminium 99.99% pure

3.1.5 Reference Point

Protective/build-up cap off:	This should be taken as on the chamber axis at 13 mm from the top of the graphite cap.
Protective/build-up cap on:	This should be taken as the intersection of the plane through the line engraved on the cap and the axis (marked with a dot).

3.1.6 Reference Line

For greater possible consistency always align the reference mark on the stem towards the source of radiation.

3.1.7 Connecting Cable Length

10 m

3.1.8 Connector Type

TNC Triaxial Free Plug

3.1.9 Accessories Supplied

Protective/build-up cap 0.3MV to 2MV.

3.1.10 Associated Electrometers

Ionex Dose/Doserate Meter 2500/3	)	do not mate directly with
Farmer Dosemeter 2502/3	)	2571A chamber (needs 2579 Adaptor)
Ionex Dosemaster 2590	)	mate directly with
Farmer Dosemeter 2570 & 2570/1	)	2571A chamber

3.1.11 Calibration Supplied

Roentgen/Coulomb at NE Qualities 4,6,9 and 11 (See 3.2.7) by direct comparison against an NPL calibrated Secondary Standard NPL Therapy Level System.

3.1.12 Additional Calibration

Roentgen/Coulomb at Co^{60} by substitution with an NPL calibrated Secondary Standard NPL Therapy Level System.

3.2 OPERATIONAL SPECIFICATION

3.2.1 Maximum Polarising Voltage

±400 V dc.

3.2.2 Conditions for the following specifications (unless otherwise stated)

Atmospheric Pressure:	1013 mbar (760 mm Hg)
Chamber Temperature:	+20°C
Polarising Voltage:	-250 V

3.2.3 Leakage Current

Typical:	$\pm 5.0 \times 10^{-15}$A	Assumes chamber in a background radiation field of 10 mRh^{-1}
Maximum:	$\pm 1.5 \times 10^{-14}$A	

3.2.4 Maximum Exposure Rate*

For 99% collection efficiency

Polarising Potential = 250 Volts: approx 4,000 R Min^{-1} continuous.; approx 0.025 R/pulse, pulses.

Polarising Potential = 400 Volts: approx 10,000 R Min^{-1} continuous.; approx 0.040 R/pulse, pulsed.

* These values are calculated according to Boag's saturation theory, but with an effective electrode spacing determined by experiment. Saturation doserates calculated on the basis of the geometric parameters of the chamber alone can be misleadingly optimistic.

3.2.5 Sensitivity

For X-rays of 1 mm Cu HVL: $4.6\ RnC^{-1}$
$275\ Rmin^{-1}\ nA^{-1}$

3.2.6 Energy Range

It is assumed that the chamber has been subjected to the appropriate calibrations (See sub-section 1.4).

3.2.6.1 X AND GAMMA RAYS

50 kV to 300 kV - without protective/build-up cap, measures exposure.

[0.3MV to 2MV, C_s^{137}, Co 60] with protective/build-up cap fitted, measures exposure.

2MV to 35MV - in suitable phantom measures absorbed dose in water.

3.2.6.2 Electrons

5MV to 35MV - in suitable phantom, measures absorbed dose in water.

3.2.7.1 ENERGY RESPONSE, X AND GAMMA RAYS

This is given in terms of Exposure in Free Air.

NE QUALITY NO. NUCLIDE	KV_p NOMINAL MeV	ADDED FILTRATION mm Sn	ADDED FILTRATION mm Cu	ADDED FILTRATION mm Al	HALF VALUE LAYER mm Cu	TYPICAL CORRECTION FACTOR RELATIVE TO Q.9
		NOT APPLICABLE				
4	60	-	-	0.17	0.046	1.035
6	100	-	-	2.0	0.15	1.015
9	180	-	0.5	1.0	1.0	1.000
11	250	0.6	0.25	1.0	3.0	1.000
Co^{60}	1.17,1.33	-	-	-	12.0	1.020

3.2.7.2 Build-Up Cap Characteristics

The Delrin protective/build-up cap has the same wall surface density (551 mg cm^{-2}) as the old perspex build-up cap 2507/3A.

For Cs^{137} and Co^{60} Gamma-rays the difference in ionisation produced in a given 2571 by the two types of build-up cap is insignificant.

3.2.8 Warm Up Time

For maximum precision, 15 minutes should be allowed after connecting the polarising voltage.

Thermal equilibrium must also be attained so that air density corrections will be accurate.

3.2.9 Pre-Irradiation Requirements

A pre-exposure of 200R is recommended.

3.2.10 Tilt Response (measured in free air)

X-rays, 1.5mm Al HVL, field dia. 4.0 cm centred on reference point.

For a tilt of the 2571 axis about the reference point ±5° from a position with the axis perpendicular to the beam axis, the variation of response in air is less than ±1.0%.

3.2.10.1 Angular Response (measured in free air)

X-rays, 1.5mm Al HVL and 3.0mm Cu HVL, field dia. 4.0 cm centred on reference point. See Figure 1.

3.2.11 Rotational Response (measured in free air)

X-rays, 1.5mm Al HVL, field dia. 4.0 cm centred on reference point. For a complete rotation of the 2571 about its axis the variation in response is less than ±0.5%.

3.2.12.1 Stem Scatter (measured in free air)

The chamber is calibrated in a field which irradiates all the thimble and approximately 12mm of the stem. Irradiation of the stem down to the threaded portion may introduce a further ±1% uncertainty, depending upon energy, because of stem scatter conditions.

3.2.12.2 Stem Leakage

Should it be necessary to irradiate the whole chamber including some of the cable, corrections should be made to allow for leakage induced during irradiation. This correction will be less than ±0.5% depending on energy and doserate.

The post-irradiation induced leakage effect is negligible.

3.2.13 Operating Temperature and Pressure

The chamber is vented and air density corrections need to be made.

3.2.14 Storage Conditions

A low humidity environment in the temperature range +10°C to + 30°C is recommended.

IONIZATION CHAMBER TYPE 233612

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

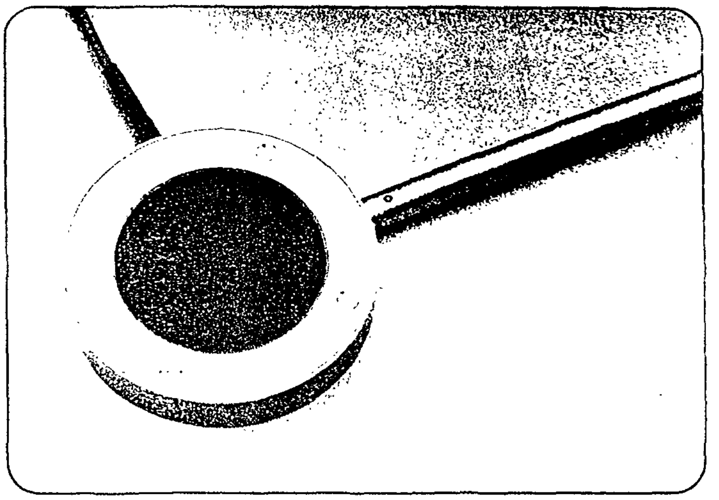
Flat chamber 30 cm³

Description

The flat ionization chamber type 233612 has been designed for measurements at diagnostic X ray qualities in air. The chamber has a separate holding stem for mounting in the radiation field.
Nominal useful range 35 keV – 75 keV.

Technical data

Volume:	30 cm³
Response:	$1 \cdot 10^{-6}$ C/Gy
Leakage:	$\pm 1 \cdot 10^{-14}$ A
Polarizing voltage:	max. 500 V
Cable leakage:	$1 \cdot 10^{-12}$ C/(Gy·cm)
Wall material:	PMMA $(C_5H_8O_2)_n$
Wall density:	1.19 g/cm³
Window thickness:	0.75 mm
Area density:	89 mg/cm²
Electrode:	PI foil, graphite coated; 47 mm Ø; 0.05 mm thick
Range of temperature:	+ 10° C ... + 40° C
Range of relative humidity:	10 % ... 80 % (< 20 g/m³)
Ion collection time:	300 V: 0.8 ms 400 V: 0.6 ms 500 V: 0.5 ms



- Guard ring up to measuring volume
- Suitable for measurements in diagnostic radiology
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device ($I_{max} < 0.5$ mA)
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 100 m available
- Connector PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	300 V	290 mGy/s	145 mGy/s
	400 V	520 mGy/s	260 mGy/s
	500 V	810 mGy/s	400 mGy/s
Max. dose per irradiation pulse	300 V	160 µGy	78 µGy
	400 V	210 µGy	100 µGy
	500 V	260 µGy	130 µGy

PTW

IONIZATION CHAMBER TYPE 77334 77337***

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

Flat Chamber 1 cm^3

Description

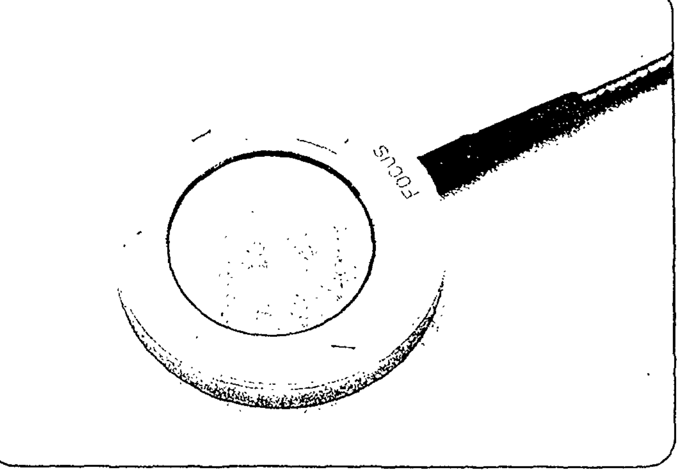
The flat chamber type 77334* (77337** resp.) is used with diagnostic dosemeters for radiography and fluoroscopy measurements during installation and maintenance of diagnostic X ray installations (especially mammagraphy equipments). Its usual calibration extends from 25 kV to 35 kV and from 50 kV to 150 kV with filtering corresponding to a position before or behind the patient. This chamber has been type tested by the PTB Braunschweig.
Nominal useful range 14 keV – 75 keV (see reverse).

* with connector PTW type M (or BNC + banana on request)

** with connector TNC or BNT

Technical data

Volume:	1.0 cm^3
Response:	$4 \cdot 10^{-8}$ C/Gy
Leakage:	$\pm 1 \cdot 10^{-14}$ A
Polarizing voltage:	max. 100 V
Cable leakage:	$1 \cdot 10^{-12}$ C/(Gy · cm)
Window material:	PI, graphite coated
Window thickness:	50 µm
Density:	1.42 g/cm^3
Area density:	7.1 mg/cm^2
Electrode:	PI foil, graphite coated; 34 mm Ø; 0.05 mm thick
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m^3)
Ion collection time:	90 V: 0.12 ms 100 V: 0.10 ms



- Guard ring up to measuring volume
- Suitable for measurements in diagnostic radiology
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device (I_{max} < 0.5 mA)
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 20 m available
- Approved for official calibration, German sign of certification:

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	90 V 100 V	14 Gy/s 17 Gy/s	7.0 Gy/s 8.6 Gy/s
Max. dose per irradiation pulse	90 V 100 V	1.1 mGy 1.2 mGy	0.5 mGy 0.6 mGy

PTW

IONIZATION CHAMBER TYPE 34001

Roos chamber 0.35 cm^3

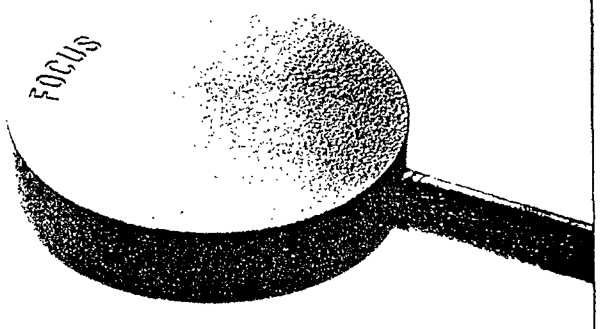
Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

Description

The Roos chamber, a development of Dr. Roos, PTB-Braunschweig, is used as a reference chamber for electron dosimetry. The Roos chamber has a wide guard ring to exclude any pertubation effect even at low electron energies. The polarity effect also is neglectable (< 0.5 % at 10 MeV). The energy dependence of the Roos chamber is only influenced by the stopping power correction; a type dependent correction is not necessary. The chamber is watertight for use in a beam analyser. The measuring volume is vented through the connection cable. The chamber can be delivered with a Cobalt-60 calibration.
Nominal useful range 2 MeV – 45 MeV.

Technical data

Volume:	0.35 cm^3
Response:	$1 \cdot 10^{-8}$ C/Gy
Leakage:	$\pm 4 \cdot 10^{-15}$ A
Polarizing voltage:	100 V recommended, 400 V max.
Cable leakage:	$3.5 \cdot 10^{12}$ C/(Gy · cm)
Wall material:	$C_5H_8O_2$ Acrylic
Wall density:	1.19 g/cm^3
Wall thickness:	1.0 mm
Area density:	119 mg/cm^2
Electrode:	Acrylic, graphite coated; 15 mm Ø
Guard ring:	4 mm wide
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m^3)
Ion collection time:	100 V: 0.37 ms 200 V: 0.13 ms 400 V: 0.07 ms



- Guarded up to the measuring volume with a 4 mm wide guard ring
- Suitable for use in solid state phantoms and in water phantoms
- Guard ring on collecting electrode potential All conductive outer parts on low potential
- High voltage to be connected only with active current-limiting device (I_{max} < 0 5 mA)
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 100 m available
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	100 V 200 V 400 V	2.6 Gy/s 11 Gy/s 42 Gy/s	1.3 Gy/s 5.2 Gy/s 21 Gy/s
Max. dose per irradiation pulse	100 V 200 V 400 V	0.5 mGy 0.9 mGy 1.9 mGy	0.2 mGy 0.5 mGy 0.9 mGy

PTW

IONIZATION CHAMBER TYPE 23343

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

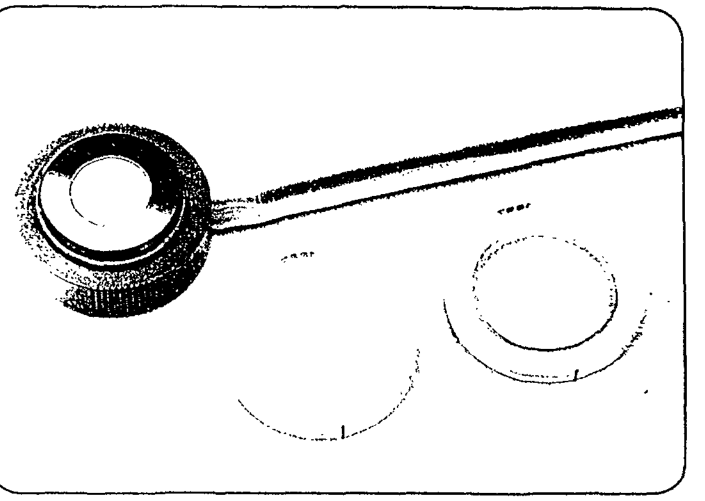
Markus Chamber 0.055 cm³

Description

The Markus chamber is the first chamber in the world specially designed for electron dosimetry. Its small measuring volume and its watertight construction make this chamber ideal for measurements in a water phantom giving a good spatial resolution. The diaphragm front allows measuring in the build up region of the electron field up to a depth of virtually zero. The measuring volume is open to the surrounding air via the connecting cable. This chamber can be delivered calibrated for absolute electron dosimetry. Nominal useful range 2 MeV – 45 MeV.

Technical data

Volume:	0.055 cm^3
Response:	$1 \cdot 10^{-9}$ C/Gy
Leakage:	$\pm 2 \cdot 10^{-16}$ A
Polarizing voltage:	300 V recommended, 400 V max.
Guard potential:	max. 100 mV
Cable leakage:	$3.5 \cdot 10^{-12}$ C/(Gy · cm)
Wall material:	CH_2 Polyethylene
Membrane thickness:	0.03 mm
Area thickness:	2.3 mg/cm^2
Electrode:	Acrylic, graphite coated; 5.3 mm Ø
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m^3)
Ion collection time:	150 V: 0.20 ms 300 V: 0.09 ms 400 V: 0.07 ms



- Guard ring up to measuring volume
- Suitable for use in solid state phantoms and with build-up cap also in water phantoms
- Guard ring and all conductive outer parts at mass potential
- Polarizing voltage to be connected only with current-limiting resistor of approx. 1 MΩ
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 100 m available
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	150 V 300 V 400 V	5.9 Gy/s 24 Gy/s 42 Gy/s	2.9 Gy/s 12 Gy/s 21 Gy/s
Max. dose per irradiation pulse	150 V 300 V 400 V	0.7 mGy 1.4 mGy 1.9 mGy	0.4 mGy 0.7 mGy 0.9 mGy

PTW

IONIZATION CHAMBER TYPE 30001

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

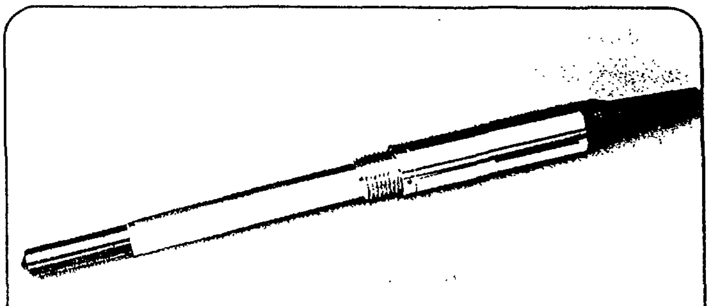
"Farmer" Chamber 0.6 cm³

Description

The 0.6 cm³ ionization chamber type 30001 is the standard chamber for absolute dosimetry for use with therapy dosemeters. This chamber is of rugged construction and equipped with an acrylic cap and an aluminium central electrode. It is fully guarded up to the measuring volume.
The outer dimensions are fully compatible with the Farmer chambers of other manufacturers.
The chamber has been type tested by PTB Braunschweig.
Nominal useful range 30 keV – 50 MeV.

Technical data

Volume:	0.6 cm³
Response:	$2 \cdot 10^{-8}$ C/Gy
Leakage:	$\pm 4 \cdot 10^{-15}$ A
Polarizing voltage:	max. 500 V
Cable leakage:	10^{-12} C/(Gy · cm)
Wall material:	PMMA $(C_5H_8O_2)_n$ + Graphite (C)
Wall density:	1.19 g/cm³ (PMMA) 0.82 g/cm³ (C)
Wall thickness:	0.275 mm PMMA + 0.15 mm C
Area density:	45 mg/cm²
Electrode:	Aluminium; 1 mm Ø; 21.2 mm long
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m³)
Ion collection time:	300 V: 0.18 ms 400 V: 0.14 ms 500 V: 0.11 ms



- Guard ring up to measuring volume
- Suitable for use in solid state phantoms; watertight sleeves available
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device (I_{max} < 0.5 mA)
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 100 m available
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	300 V	5.7 Gy/s	2.8 Gy/s
	400 V	10 Gy/s	5.0 Gy/s
	500 V	16 Gy/s	7.8 Gy/s
Max. dose per irradiation pulse	300 V	0.69 mGy	0.34 mGy
	400 V	0.91 mGy	0.46 mGy
	500 V	1.14 mGy	0.57 mGy

PTW

IONIZATION CHAMBER TYPE 31003

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

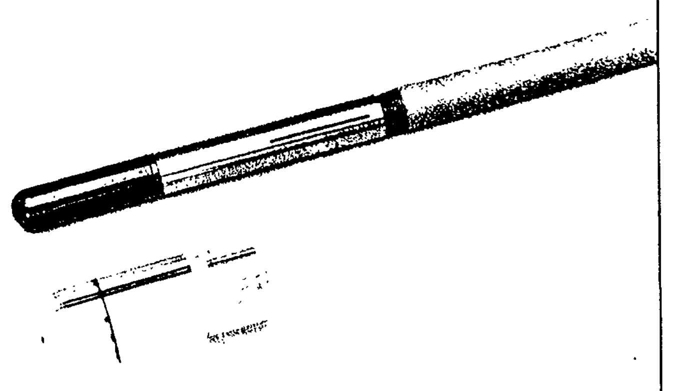
Flex Tube Chamber 0.3 cm³

Description

The ionization chamber type 31003 has been designed for measurements in the useful beam of high energy photon or electron fields. The chamber is watertight and used mainly for relative measurements with a water phantom or air scanner for characterization of the radiation fields of therapy accelerators and teletherapy cobalt sources. The measuring volume is open to the surrounding air via cable and connector. The chamber has a short rigid stem for mounting and a flexible connection cable. This chamber has been type tested by the PTB Braunschweig.
The design of the chamber is similar to the 0.125 cm³ chamber type 31002 but with a larger volume for higher response. Nominal useful range 30 keV – 50 MeV.

Technical data

Volume:	0.3 cm³
Response:	$1 \cdot 10^{-8}$ C/Gy
Leakage:	$\pm 4 \cdot 10^{-15}$ A
Polarizing voltage:	max. 500 V
Cable leakage:	$1 \cdot 10^{-12}$ C/(Gy · cm)
Wall material:	PMMA $(C_5H_8O_2)_n$ + Graphite (C)
Wall density:	1.19 g/cm³ (PMMA) 0.82 g/cm³ (C)
Wall thickness:	0.55 mm PMMA + 0.15 mm C
Area density:	78 mg/cm²
Electrode:	Aluminium, graphite coated; 1.5 mm Ø; 14.25 mm long
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m³)
Ion collection time:	300 V: 0.10 ms 400 V: 0.08 ms 500 V: 0.06 ms



- Guard ring up to measuring volume
- Suitable for use in solid state phantoms and water phantoms
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device (I_{max} < 0.5 mA)
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 100 m available
- Approved for official calibration, German sign of certification: 23 21 / 65 1
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	300 V	17 Gy/s	7.5 Gy/s
	400 V	29 Gy/s	13 Gy/s
	500 V	45 Gy/s	21 Gy/s
Max. dose per irradiation pulse	300 V	1.1 mGy	0.6 mGy
	400 V	1.5 mGy	0.8 mGy
	500 V	1.9 mGy	1.1 mGy

PTW

IONIZATION CHAMBER TYPE 31002

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

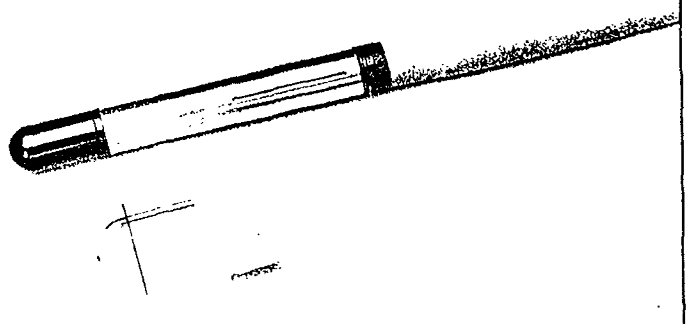
Semiflex Tube Chamber 0.125 cm³

Description

The 0.125 cm³ ionization chamber type 31002 is designed for measurements in the useful beam of high energy photon or electron fields. The chamber is watertight and used mainly for relative measurements with a water phantom or air scanner for characterization of the radiation fields of therapy accelerators and teletherapy cobalt sources. The measuring volume is open to the surrounding air via cable and connector. The measuring volume is approximately spherical resulting in a flat angular response over an angle of 160° and a uniform spatial resolution during phantom measurements along all three axis. The chamber has a short rigid stem for mounting and a flexible connection cable. Nominal useful range 30 keV – 50 MeV.

Technical data

Volume:	0.125 cm³
Response:	$4 \cdot 10^{-9}$ C/Gy
Leakage:	$\pm 4 \cdot 10^{-15}$ A
Polarizing voltage:	max. 500 V
Cable leakage:	10^{-12} C/(Gy · cm)
Wall material:	PMMA $(C_5H_8O_2)_n$ + Graphite (C)
Wall density:	1.19 g/cm³ (PMMA) 0.82 g/cm³ (C)
Wall thickness:	0.55 mm PMMA + 0.15 mm C
Area density:	78 mg/cm²
Electrode:	Aluminium; 1 mm Ø; 5 mm long
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m³)
Ion collection time:	300 V: 0.14 ms 400 V: 0.10 ms 500 V: 0.08 ms



- Guard ring up to measuring volume
- Suitable for use in solid state phantoms and water phantoms
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device (I_{max} < 0.5 mA)
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 100 m available
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	300 V	5.6 Gy/s	2.8 Gy/s
	400 V	10 Gy/s	5.0 Gy/s
	500 V	15 Gy/s	7.5 Gy/s
Max. dose per irradiation pulse	300 V	0.7 mGy	0.4 mGy
	400 V	1.0 mGy	0.5 mGy
	500 V	1.2 mGy	0.6 mGy

PTW

IONIZATION CHAMBER TYPE 23323

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

Micro Chamber 0.1 cm^3

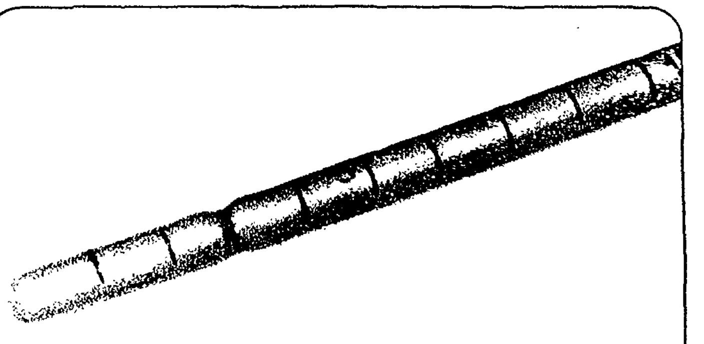
Description

The ionization chamber type 23323 has been designed for use with therapy dosemeters as a standard sealed chamber. It is watertight and equipped with a flexible stem so it can be used in variable temperature surroundings. The usual calibration is done at 280 kV X-ray and ^{137}Cs, so ^{192}Ir calibration can be obtained by interpolation[1], or 140 kV to ^{60}Co for general purpose use. The measuring volume is sealed to the surrounding air (according to IEC 731). Nominal useful range 60 keV – 50 MeV.

1 Literature: Zt. med. Phys., 4/1991, page 194

Technical data

Volume:	0.10 cm^3
Response:	$3.8 \cdot 10^{-9}$ C/Gy
Leakage:	$\pm 4 \cdot 10^{-15}$ A
Polarizing voltage:	max. 500 V
Cable leakage:	$1 \cdot 10^{-12}$ C/(Gy · cm)
Wall material:	Rubber + PMMA $(C_5H_8O_2)_n$ + Graphite (C)
Wall density:	1.20 g/cm^3 (Rubber) 1.19 g/cm^3 ((PMMA) 0.82 g/cm^3 (C)
Wall thickness:	0.95 mm Rubber + 0.613 mm PMMA + 0.125 mm C
Area density:	197 mg/cm^2
Electrode:	Aluminium, graphite coated; 0.8 mm Ø; 10 mm long
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m^3)
Ion collection time:	300 V: 0.04 ms 400 V: 0.03 ms 500 V: 0.02 ms



- Guard ring up to measuring volume
- Suitable for use in solid state and water phantoms
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device (I_{max} < 0.5 mA)
- Measuring volume air-tight for 8 hours
- Lengthening cable up to 100 m available
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	300 V	125 Gy/s	62 Gy/s
	400 V	225 Gy/s	110 Gy/s
	500 V	350 Gy/s	175 Gy/s
Max. dose per irradiation pulse	300 V	3.2 mGy	1.6 mGy
	400 V	4.3 mGy	2.1 mGy
	500 V	5.4 mGy	2.7 mGy

PTW

IONIZATION CHAMBER TYPE 23322

C Chamber 0.1 cm³

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

Description

The ionization chamber type 23322 has been designed for use with therapy dosemeters in variable temperature surroundings. It is watertight and equipped with a flexible stem. The usual calibration is done at 280 kV X-ray and ^{137}Cs, so ^{192}Ir calibration can be obtained by interpolation[1]. The measuring volume is sealed to the surrounding air (according to IEC 731). For absolute measurements the chamber is therefore only to be used with a check source. Nominal useful range 140 keV – 50 MeV.

1 Literature: Zt. med. Phys., 4/1991, page 194

Technical data

Volume:	0.10 cm^3
Response:	$3.8 \cdot 10^{-9}$ C/Gy
Leakage:	$\pm 4 \cdot 10^{-15}$ A
Polarizing voltage:	max. 500 V
Cable leakage:	$1 \cdot 10^{-12}$ C/(Gy · cm)
Wall material:	Polyolefine + PMMA $(C_5H_8O_2)_n$ + Graphite (C)
Wall density:	1.07 g/cm^3 (Polyolefine) 1.19 g/cm^3 (PMMA) 0.82 g/cm^3 (C)
Wall thickness:	0.45 mm Polyolefine + 0.59 mm PMMA + 0.125 mm C
Area density:	129 mg/cm^2
Electrode:	Aluminium, graphite coated; 0.8 mm Ø; 10.5 mm long
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m^3)
Ion collection time:	300 V: 0.04 ms 400 V: 0.03 ms 500 V: 0.02 ms

- Guard ring up to measuring volume
- Suitable for use in solid state, water phantoms and for intracavitary use
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device (I_{max} < 0.5 mA)
- Measuring volume air-tight for 8 hours
- Lengthening cable up to 100 m available
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	300 V 400 V 500 V	125 Gy/s 225 Gy/s 350 Gy/s	62 Gy/s 110 Gy/s 175 Gy/s
Max. dose per irradiation pulse	300 V 400 V 500 V	3.2 mGy 4.3 mGy 5.4 mGy	1.6 mGy 2.1 mGy 2.7 mGy

PTW

IONIZATION CHAMBER TYPE 23344

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

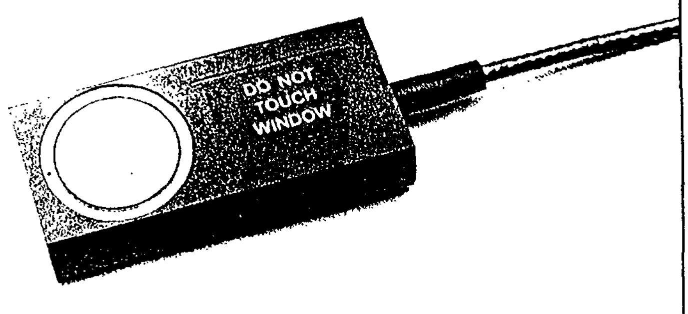
Big Soft-X-Ray Chamber 0.2 cm^3

Description

The soft X-ray ionization chamber type 23344 is an alternative chamber for measurements in superficial therapy or mammography, where a higher response is necessary. It can be used in air or in solid phantoms. The usual calibration is done at 15 kV to 70 kV. The measuring volume is open to the surrounding air. This chamber has a very flat energy dependance from 10 kV to 100 kV. Nominal useful range 8 keV – 35 keV.

Technical data

Volume:	0.20 cm^3
Response:	$7 \cdot 10^{-9}$ C/Gy
Leakage:	$\pm 1 \cdot 10^{-14}$ A
Polarizing voltage:	max. 500 V
Cable leakage:	$1 \cdot 10^{-12}$ C/(Gy · cm)
Wall material:	PE $(CH_2)_n$
Membrane thickness:	0.03 mm
Area density:	2.5 mg/cm^2
Electrode:	0.1 mm Al on Graphite 13 mm Ø
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m^3)
Ion collection time:	300 V: 0.05 ms 400 V: 0.04 ms 500 V: 0.03 ms



- Guard ring up to measuring volume
- Suitable for use in solid state phantoms
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device (I_{max} < 0.5 mA)
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 100 m available
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	300 V 400 V 500 V	75 Gy/s 130 Gy/s 210 Gy/s	37 Gy/s 66 Gy/s 100 Gy/s
Max. dose per irradiation pulse	300 V 400 V 500 V	2.5 mGy 3.3 mGy 4.2 mGy	1.2 mGy 1.7 mGy 2.1 mGy

PTW

IONIZATION CHAMBER TYPE 23342

Radiation Therapy
Diagnostic Radiology
Nuclear Medicine
Radiation Protection

Small Soft-X-Ray Chamber 0.02 cm³

Description

The soft X-ray ionization chamber type 23342 is the standard chamber for measurements in superficial therapy. It can be used in air or in solid phantoms (e.g. phantom type T2962). The usual calibration is done at 15 kV to 70 kV. This chamber has a very flat energy dependence from 10 kV to 100 kV. This chamber is type tested by the PTB Braunschweig, the Federal Institute of Physics and Metrology. Nominal useful range 8 keV – 35 keV.

Technical data

Volume:	0.02 cm^3
Response:	$3 \cdot 10^{-10}$ C/Gy
Leakage:	$\pm 1 \cdot 10^{-14}$ A
Polarizing voltage:	300 V recommended, 400 V max.
Cable leakage:	$1 \cdot 10^{-12}$ C/(Gy · cm)
Wall material:	PE $(CH_2)_n$
Membran thickness:	0.03 mm
Area density:	2.5 mg/cm^2
Electrode:	0.1 mm Al on Graphite; 3 mm Ø
Range of temperature:	+ 10° C ... + 40° C
Range of rel. humidity:	10 % ... 80 % (< 20 g/m^3)
Ion collection time:	150 V: 0.04 ms 300 V: 0.02 ms 400 V: 0.02 ms

- Guard ring up to measuring volume
- Suitable for use in solid state phantoms
- Guard ring at potential of the collecting electrode. Touchable parts free of high voltage
- High voltage to be connected only with active current-limiting device (I_{max} < 0.5 mA)
- Open measuring volume, without check device air density correction is necessary
- Lengthening cable up to 100 m available
- Approved for official calibration, German sign of certification:
- Connector: PTW type M, TNC or BNT (BNC + banana on request)

Saturation behaviour	Polarizing voltage	99.0 % saturation	99.5 % saturation
Max. dose rate at continuous irradiation	150 V 300 V 400 V	95 Gy/s 380 Gy/s 670 Gy/s	47 Gy/s 190 Gy/s 335 Gy/s
Max. dose per irradiation pulse	150 V 300 V 400 V	2.8 mGy 5.6 mGy 7.5 mGy	1.4 mGy 2.8 mGy 3.7 mGy

PTW

OPERATORS MANUAL

Patient Dose Verification System

Model TN-RD-50

THOMSON & NIELSEN ELECTRONICS LTD.

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Document #100237.02 — *Second Publication August 1994*
Document #100237.03 — *Third Publication February 1995*

Section 3

THEORY OF OPERATION

3.1 INTRODUCTION

This section describes the basic theory of operation of the Patient Dose Verification System. Included are an overall functional description, technical data on sensor operation, and information on the bias supply, Reader and calibration holder.

3.2 OVERALL FUNCTIONAL DESCRIPTION

Figure 3-1 represents a simplified hardware function block diagram for the Patient Dose Verification System. While the most important block connections have been shown, many interconnections have been omitted in order to maintain clarity.

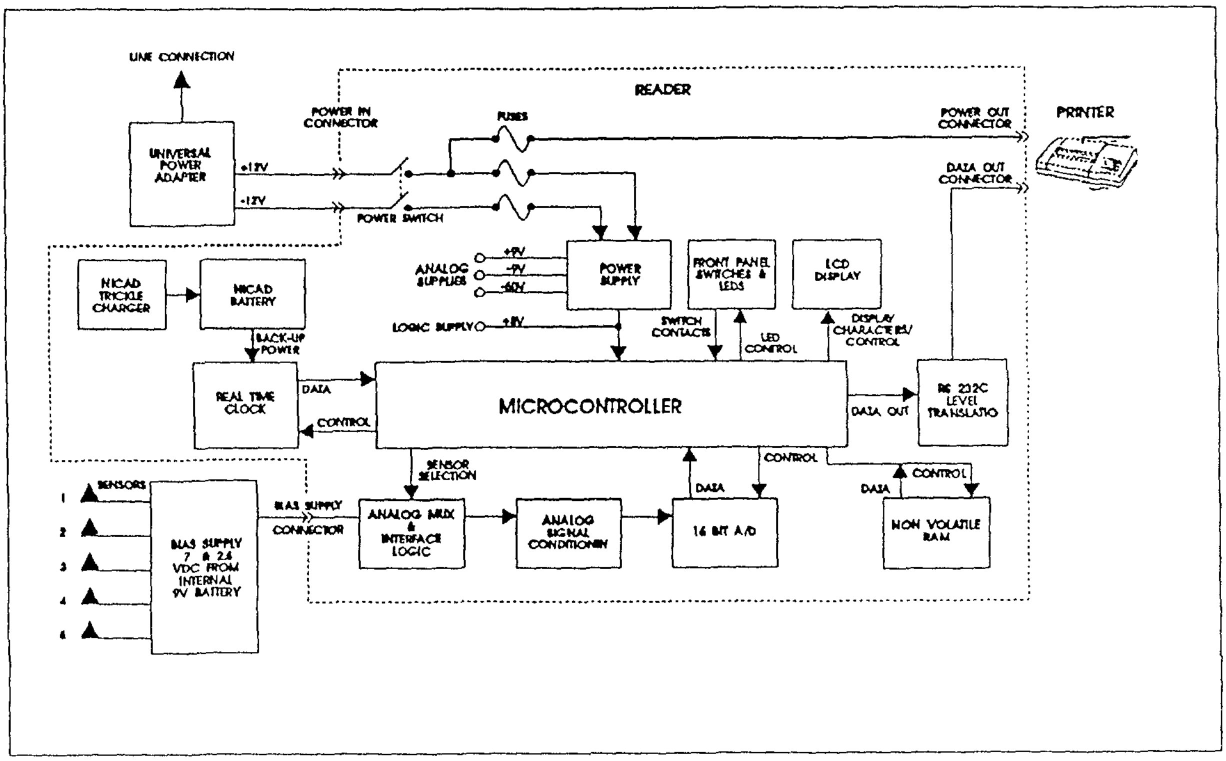

Figure 3-1. System Block Diagram

3.3 SENSORS

The sensor is composed of a 1.5 meter length of flat cable attached to 20 centimetres of thin semi-opaque acrylic laminate. The detector is mounted on the end of the acrylic material and encapsulated under approximately 2mm of black epoxy. Electrical connection to the detector is provided by flexible circuit board-like tracks embedded in the acrylic.

Important

The acrylic laminate and epoxy are intended to be the only sensor materials that directly contact the patient. These are the only sensor materials on which the low level disinfection procedure specified in this manual has been validated.

The detector is a proprietary MOSFET semiconductor device whose threshold voltage is permanently increased with exposure to radiation. Threshold voltage is defined as the minimum gate voltage required to cause the MOSFET to conduct current from source to drain. The threshold voltage is measured during each "ZERO" and "READ" process and reported as the "TOTAL". The dose delivered during an exposure is determined by subtracting the pre-exposure total from the post-exposure total. The resulting voltage difference is termed the exposure-induced voltage shift and is the source of the reported "DOSE". A calibration factor may automatically be applied to the exposure-induced voltage to report the dose in units of cGy or RAD. If no calibration factor is selected, the dose is reported in millivolts (shown as mV).

The sensitivity and response to ionizing radiation depend to some extent on the bias voltage applied at the time of irradiation. The gate-to-source bias voltage applied is approximately seven volts, which produces a voltage shift of approximately 1mV per cGy under full buildup and approximately 0.5 mV/cGy without buildup. Measurement accuracy of the sensor depends on the size of the exposure-induced voltage shift. In general large delivered doses and/or the use of buildup produce large voltage signals with higher measurement accuracy.

Also affecting accuracy, particularly at low dose fractions on sensors with high total accumulated doses, is a phenomenon known as "fading". Fading is a gradual change in sensor voltage with time since exposure, until a stable voltage is reached. In normal clinical applications using measurement techniques recommended in this manual, fading should not be a significant factor. The amount of fading after a clinical level exposure increases with total accumulated sensor voltage, so fade contributes the most error when a)the total accumulated dose is high, b)the dose fraction is small, and c)the times between zeroing, exposure, and reading are relatively long. Also, a high exposure of several thousand units can temporarily result in large fade values.

Optimum stability will be achieved if the sensors remain connected to the bias supply. Use of fresh sensors, or sensors that have been stored off-bias should be delayed by one hour minimum after connection to the Bias Supply.

The sensor voltage is a nearly linear function of accumulated exposure to approximately 20,000 millivolts, after which the sensor voltage saturates and the response to further irradiation becomes non-linear. The slope of the curve describing sensor voltage as a function of accumulated exposure is the calibration factor. For typical sensors, the calibration factor as a function of accumulated exposure shows a parabolic shape (highest at mid-life) whose peak-to-peak excursion is less than four percent of a 200 unit exposure over the expected life of 20,000 mV. For a higher degree of accuracy, sensors may be recalibrated about every 7,000 millivolts of exposure.

3.3 SENSORS (Continued)

Sensor response as a function of beam incidence angle (polar anisotropy) is uniform around the lo· axis of the sensor and has a peak-to-peak increase of 14% centered at normal to the inherent build-ı (epoxy) area of the sensor. For flat response, irradiating the flat side of the sensor for calibration a. measurement is recommended. For maximum signal, irradiating the inherent build-up side of t!· sensor is recommended, but the polar anisotropy effect is greatest for exposure to this side.

Figure 3-2 shows the relatively flat response of the sensor to photons and electrons as a function c energy in the region of radiation therapy.

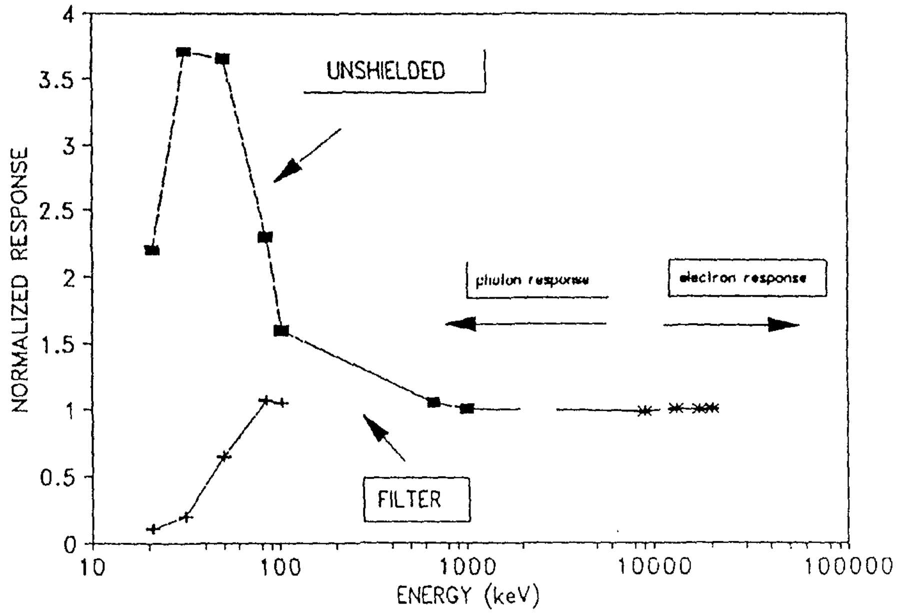

Figure 3-2. Energy response normalized to ^{60}Co

3.4 BIAS SUPPLY

The main function of the bias supply (see Figure 3-3 below) is to provide a regulated bias voltage tc the sensors. Therefore, this essential component contains a long-life nine-volt lithium battery anc associated electronics. The bias supply also incorporates a red "LOW BATTERY" light which provided that the battery is not completely discharged, warns the operator of a low (flashing) o critical (continuous) battery voltage condition. The bias supply battery will last approximately one year under normal operating conditions.

Important

Operators should avoid placing bias supplies in the radiation field. However, inadvertent exposure of bi supplies is not detrimental, provided the total accumulated lifetime dose does not exceed 20,000 cGy.

3.4 BIAS SUPPLY(Continued)

A secondary function is to provide a convenient interface from the sensors to the Reader via a one-meter long cable. **Connection of the bias supply to the Reader is necessary only for "ZEROING" and "READING" the sensors. Do not maintain patient contact with the sensors when the bias supply is connected to the Reader.**

The system can manage up to four independent bias supplies one at a time, which are electronically labeled "A","B", "C" or "D" via an internal jumper setting. Electronic labeling of the bias supplies is in-field configurable (see section 4.3).

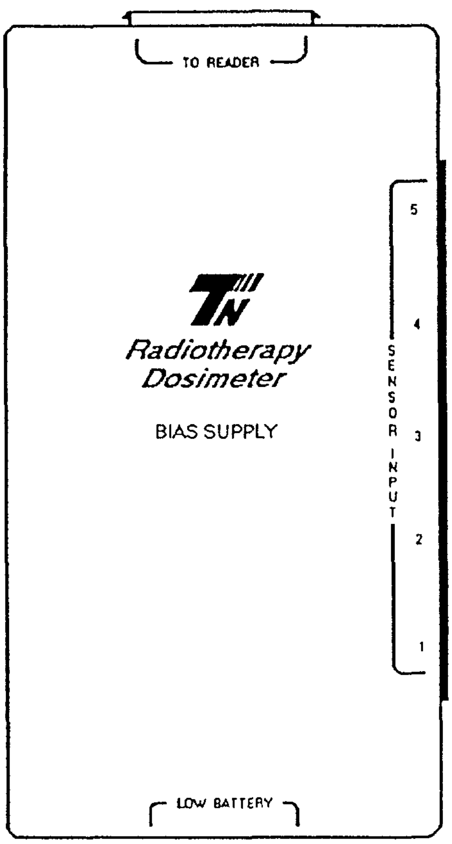

Figure 3-3 Bias Supply Top View

PTW

Instruction Manual

Solid Phantom Type 29672

[468.131.0/1]

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HRB NR 1673
General Manager:
Dr. Edmund Schüle,
Dr. Christian Pychlau

2 Measurement hints

2.1 General

The solid slab phantom type 29672 can be used for depth dose measurements and the calibration of thimble and parallel plate chambers in the range from ^{60}Co Gamma radiation and Photon radiation up to 50 MV and electron radiation from 4 MeV to 50 MeV in the unit of absorbed dose to water.

The calibration of a chamber in the phantom can be done with ^{137}Cs and ^{60}Co Gamma radiation by interchanging a reference chamber against the chamber under calibration. That means, the irradiation of both chambers is done one after the other in the same geometry.

In case of Bremsstrahlung, the same procedure needs a high constancy of the tube voltage of the X-ray unit or accelerator. If the measurement is made against a monitor, which has its chamber in air between the focus and the chamber under calibration in the phantom, small changes of the tube voltage will cause changes of the Bremsstrahlung spectrum and thereby different absorption in that part of the phantom which is between the monitor in air and the chamber under calibration in a certain depth.

2.2 Field inhomogeneity

The solid slab phantom type 29672 can be used for simultaneous measurement of more than one chamber with special adaptors. When using more than one chamber due to possible field inhomogeneities the chambers should be exchanged in their position to obtain equivalent doses in the comparison of the chambers.

When using chambers of different construction at the same time, the possibility of a mutual influencing of the radiation field should be considered; this is not necessary when comparing two chambers of the same construction since mutual influences then are equivalent.

Hint:
Different scattering due to different chamber construction could be investigated for instance by calibrating the chambers versus a monitor transmission chamber but radiation quality constancy has to be observed when using this method (see above).

When irradiating several chambers the necessary field size should be observed.

2.3 Remarks on the use of RW3 for measurements "in water"

Water is the standard reference material in high energy photon and electron dosimetry and should be used in the first or basic dosimetry. But, in many applications such as routine or constancy checks it is often more convenient to work with a solid water equivalent phantom material.

RW3 is a white polystyrene material containing 2 % by mass TiO_2. RW3 has been developed for the use as solid water in high energy photon and electron dosimetry. Different admixtures of TiO_2 have been studied systematically to optimize for the purpose of dosimetry (7).

RW3 is delivered in slabs of size 30 cm x 30 cm with thicknesses of 1 mm, 2 mm, 5 mm and 10 mm. The nominal thickness is guaranteed within ± 0.1 mm. Different slabs with a hole cast to the dimensions of all PTW chambers and FeS-ampoules are available. The mass density of RW3 is 1.045 g/cm³, $(Z/A)_{eff}$ amounts 0.536 and the electron density has a factor relative to water of 1.012.

In dosimetry material equivalence means the same characteristics of two materials with respect to absorption and scattering of photons and electrons. The lower effective atomic number of polystyrene relative to water can be partially balanced by the high atomic number of TiO_2. Because of the energy dependence of the absorption and scattering coefficients it is obvious that this compensation cannot hold over all energy levels used in high energy radiation dosimetry.

Different experimental setups have been developed to investigate material equivalence and to determine correction factors (5, 9, 10, 11).

2.4 Correction Factors for Photons

2.4.1 Absolute Dosimetry

Using RW3 as solid water, i.e. with the same correction factors normally applied to dose measurements performed in water, any difference in the absolute ionization between the reading in water and RW3 yields the same difference in the absolute absorbed dose measured. It is known that with respect to water the ionization in clear and white polystyrene is lower. Values between 0 % and 5 % have been published (8, 12).
Introducing a correction factor $h_{w,p}$

$$h_{w,p} = M_w/M_p \qquad (1)$$

where Mw and Mp are the ionization in water and polystyrene, respectively, the dependence of energy, depth and field size can be demonstrated. The two following figures show this correction factor for four different beam qualities and two field sizes as a function of depth.

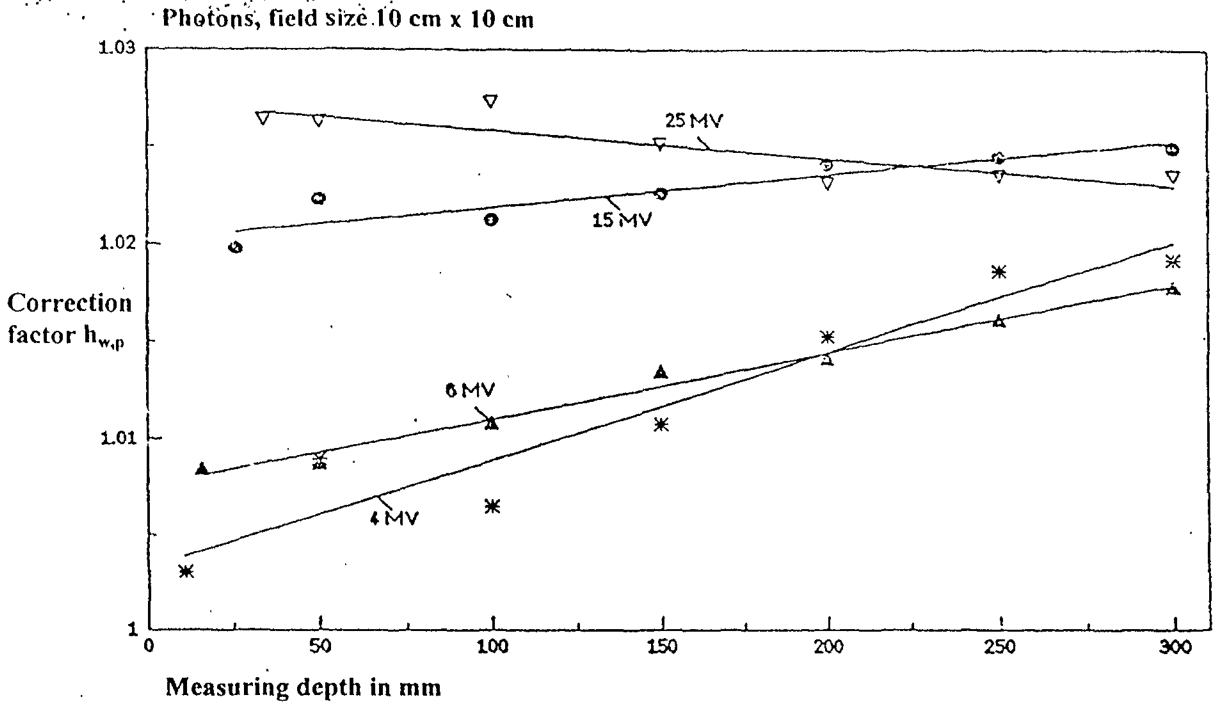


Figure 4: *The correction factor $h_{w,p}$ as a function of depth for the field size 10 cm x 10 cm*

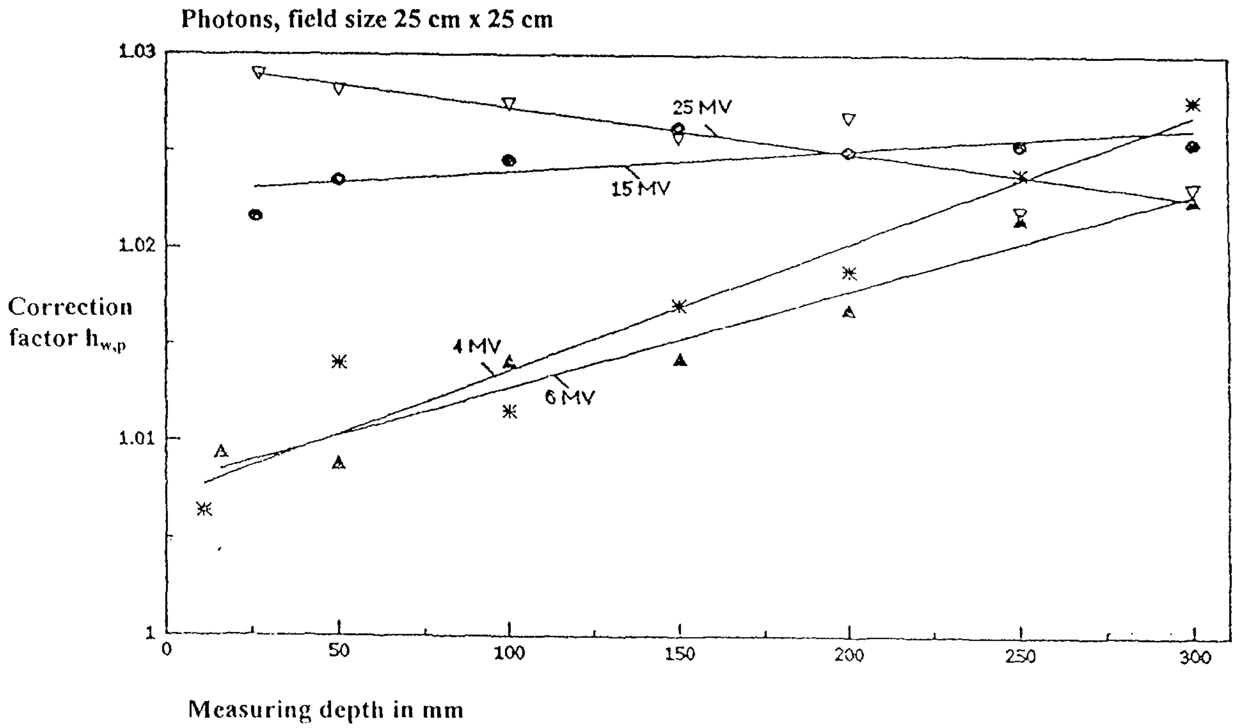


Figure 5: *The correction factor $h_{w,p}$ has a function of depth for the field size 25 cm x 25 cm*

The results of figure 4 and 5 are influenced by several parameters such as type of ionization chamber used, spectral distribution of photons at the point of measurement, and others. The user is therefore strongly recommended to check these data for the particular conditions of interest (see section 4).

2.4.2 Relative Dosimetry

The data from figure 4 and 5 can be used to estimate the deviations in TMR or relative depth dose between water and RW3. It is obvious that a correction factor constant with depth results in no deviations in relative measurements. It can be shown that the percentage deviation in TMR $\Delta(z)$ (normalized to maximum dose) in the depth z is approximately

$$\Delta(z) = (h_{w,p}(z) - h_{w,p}(z_{max}))\ TMR(z) \qquad (2)$$

where $h_{w,p}(z_{max})$ is the correction factor in the depth of maximum ionization. For TMR(z) either the value measured in water or in RW3 can be selected.

Combining the well known TMR data for the given beam qualities with the data from figure 4 and 5, at field size 10 cm x 10 cm no greater percentage deviations than 0.5 % (4 MV), 0.4 % (6 MV), 0.3 % (15 and 25 MV) occur. Slightly higher values are found at field size 25 cm x 25 cm: 0.7 % (4 MV), 0.6 % (6 MV), 0.5 % (15 and 25 MV).

As an example, the determination of the beam quality factor Q from measurements in RW3 may be investigated. The deviation in Q amounts to less than 0.6 % (4 MV), 0.4 % (6 MV) and 0.2 % (15 MV and 25 MV) caused by a deviation of the stopping power ratio water to air ($s_{w,air}$) of about 0.03 % (4 MV and 6 MV), 0.04 % (15 MV) and 0.05 % (25 MV).

2.5 Correction Factors for Electrons

2.5.1 Absolute Dosimetry

On account of the lower angular scattering power of RW3 the absolute ionization is too low. The same correction factor $h_{w,p}$ as made before for photons can be introduced:

$$h_{w,p} = M_w(z_{max}) / M_p(z_{max}) \qquad (3)$$

where $M_w(z_{max})$ and $M_p(z_{max})$ are the readings in the depth of maximum ionization in water and RW3, respectively. The energy dependence of this correction factor is shown in figure 6.

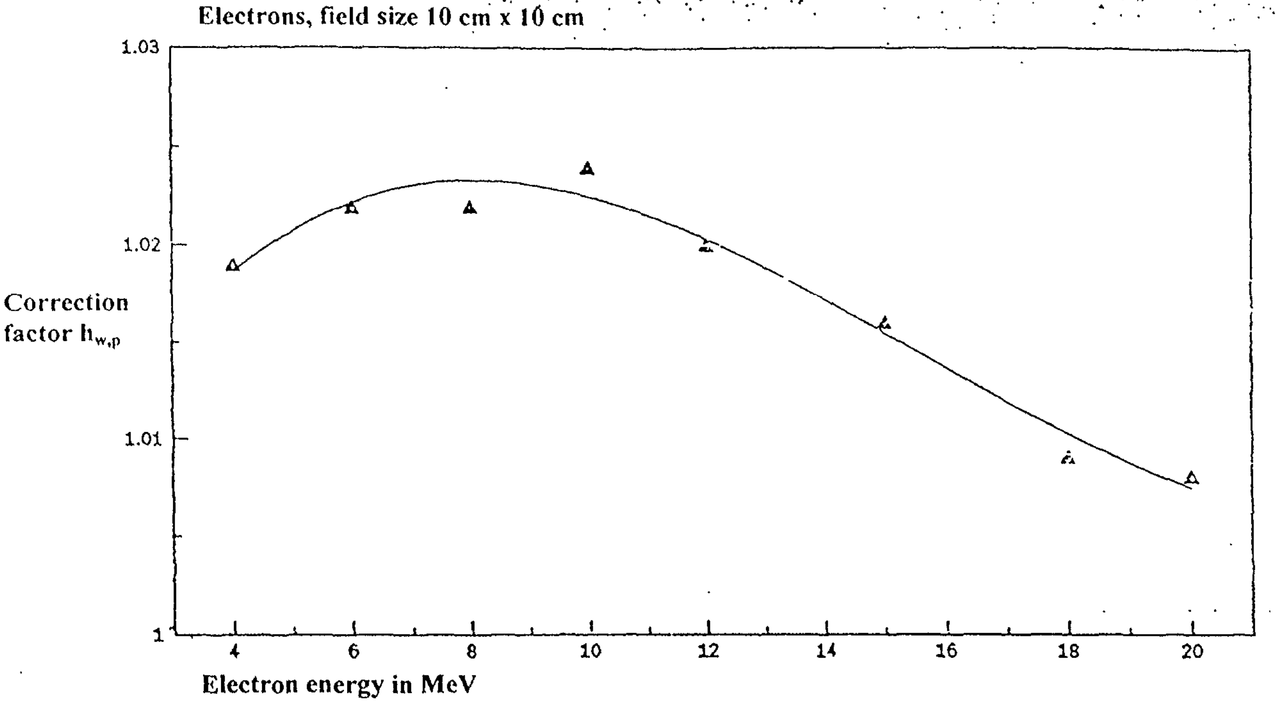


Figure 6: *The correction factor $h_{w,p}$ in the depth of maximum ionization as a function of electron energy.*

As mentioned before for photons, the data of figure 6 depends on the type of ionization chamber, scattering foils, type of applicator, field size, energy and angular spread of electrons and others (4). It is therefore strongly recommended that these data are verified in the users beam (see section 4).

2.5.2 Relative Dosimetry

For electrons within 4 MeV and 20 MeV, deviations in relative profile measurements are negligible as has been confirmed by several authors (7, 10, 12). Deviations of less than 1 mm are described. It follows from this that energy parameters gained from measurements in RW3 are determined with sufficient accuracy showing a tendency to slightly higher values.

2.5.3 Comparative Measurements in RW3 and Water

The water equivalent solid phantom material RW3 can be easily used for high energy photon and electron dosimetry as a substitute for water. Relative profile measurements are in good agreement with those measured in water. For determination of absolute dose a correction factor greater than unity must be applied for both photons and electrons. This correction factor shows a dependence on several parameters such as energy and spectral distribution, depth of measurement, field size, type of ionization chamber and others.

It is therefore recommended that the user takes the results presented here as guidelines only. Control measurements should be performed under routine conditions.

There are some points that must be taken into account:

1. Water phantom and RW3 phantom should be in temperature equilibrium.
2. Evaporation of water reduces water temperature and possibly the depth of the chamber in water.
3. The true thickness of the RW3 slabs must be known.
4. If the RW3 slabs are not totally flat air gaps between the slabs may occur. Especially for measurements with constant source-surface distance the source-detector distance may be influenced by this.
5. The long-time stability of the dosimetry system must be checked.

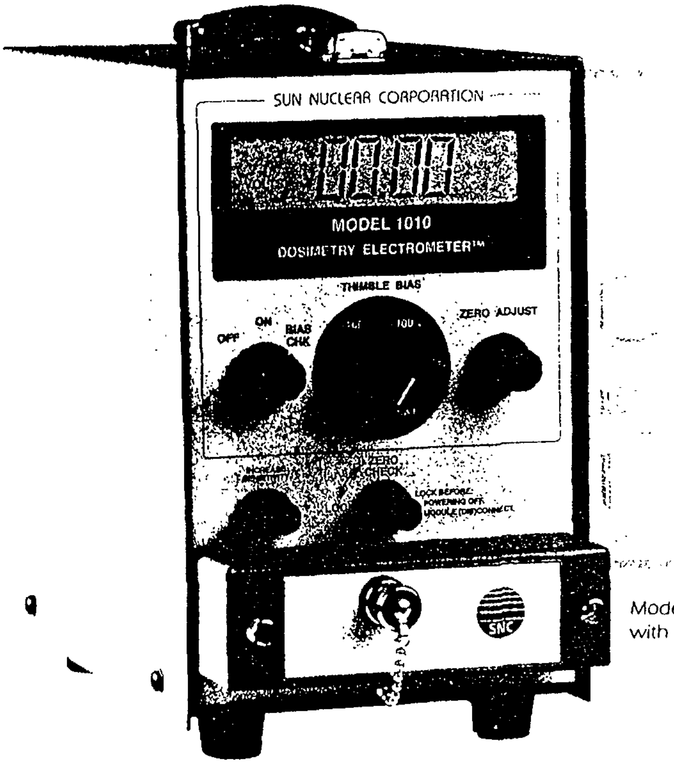
Attention

Continuous long-time irradiation can cause static charges in solid phantom materials. To avoid eventual display error resulting from this, the maximum plate thickness should be 10 mm. The plates should be discharged by regularily wiping with a metallic edge connected to ground potential whenever the dose in the phantom has reached approx. 40 Gy.

Precision

DOSIMETRY ELECTROMETER™

"Classic Simplicity Improved Through Updated Technology"



Model 1010 with feedback module

- **VERSATILITY** - "You customize to your need." The versatility of the **Model 1010** stems from its innovative modular design. The amplifier feedback element is contained in a removable module.

- **RELIABILITY** - Rugged design combined with battery operation, hybrid ranging, and an internal electronic bias supply, all contribute to the high degree of performance offered by the **Model 1010**.

- **SIMPLE** - With its controls, input and 0.7 inch high digital LCD display all located on the front panel, the **Model 1010** has condensed the user interface to the bare essentials without compromising features.

- **ECONOMICAL** - "You only buy what you need." The modular design means that you save money by not paying for ranges that you will not use. The flexibility of design insures that your investment need not be abandoned as your needs change.

Precision Dosimetry Electrometer™

The **Model 1010** Dosimetry Electrometer, a reference grade instrument, maintains the simplicity of classic electrometer styling while utilizing contemporary design and state-of-the-art electronics.

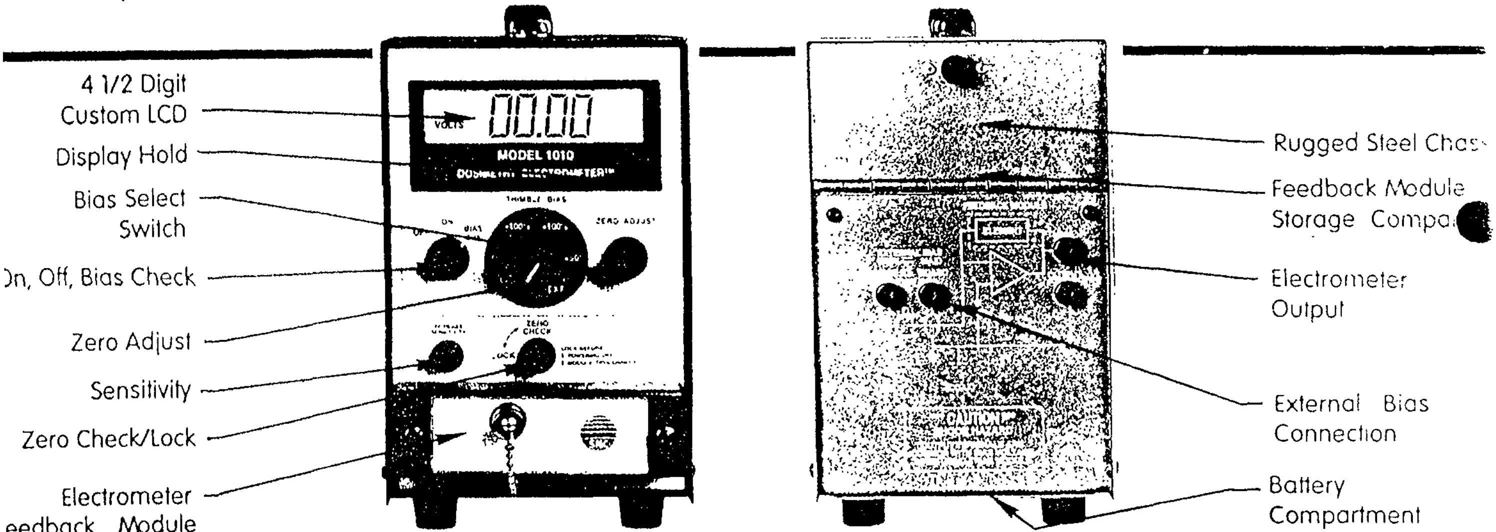
The **Model 1010** is **SIMPLE** to operate. All controls are located on the front panel. The nomenclature is clear and concise. The value is displayed in easy-to-read 0.7 inch digits. A tilt bail is provided for optional viewing angle. Yet, the **Model 1010** has a broad range of operation and can accomodate any size ion chamber utilizing most types of connectors.

The **VERSATILITY** of the **Model 1010** stems from its innovative modular design. The amplifier feedback element is contained in an external module. The module is removable and can be exchanged with any number of modules. Each module changes the measurement features of the electrometer. In this way, a single electrometer can be configured to satisfy a wide range of applications,

In addition, each module is individually calibrated. By pairing an ion chamber with a specific module, full calibration of all chambers on a single electrometer can be acheived.

The **Model 1010** is designed for long term **RELIABILITY.** Low leakage currents are acheived due to the selection of special components and the implementation of proprietary production techniques. All feedback elements are extensively evaluated to insure long-term stability. Standard "D" cell batteries provide over 1,000 hours of continuous operation and around-the-clock power to the electrometer circuit.

The combination of simplicity and versatility make the **Model 1010** one of the most **ECONOMICAL** electrometers on the market today. The innovative modular design and the classic simple styling means that, with the **Model 1010**, you only purchase what you need.



SPECIFICATIONS (subject to change without notice)

DISPLAY: 0.7 inch, 4 1/2 digit custom LCD display, with floating decimal point, display hold and low battery indications.
DISPLAY UPDATE: 1 sec
UNITS: Module selected - Electrometry (pA, nA, μA, pC, nC)
Dosimetry (R or Gy with μ, m, c prefix) (Rate in s, min, h)
INPUT: Triax or Coax
INPUT LEAKAGE CURRENT: Less than 5 fA
PREAMP OUTPUT: ± 2 Volt; banana jack (back panel)
ELECTROMETER INPUT OFFSET: Adjustable to within ± 5mv
FRONT PANEL CONTROLS: Power Switch - off, on, bias check
Bias Selector - off, -50%, -100%, +100%, +50%, Ext
Zero Adjust - 10 turn pot, ± 200 μV range
Display Hold - momentary switch
Reset - momentary and twist-to-lock (< 1 sec discharge)
Increase sensitivity - momentary switch
BIAS: Internal electronic bias - 100% = 300 V nominal
External Bias - via banana jack (back panel)
RANGES: Three decade auto-ranging up
POWER: Six 'D' cell batteries, over 1,000 hours of continuous operation
DIMENSIONS: 9" (23 cm) high x 5.2" (13.2 cm) wide x 10" (25 cm) deep
WEIGHT: 10.5 Pounds, (4.8 kg)

ELECTROMETER RANGES:
CURRENT: ± 0.001 pA to ± 1999.9 μA (13 decades)
CHARGE: ± 0.0001 pC to ± 1999.9 nC (12 decades)
When ordering, specify input connector and full scale requirement for each module.
DOSIMETRY RANGES: For any ion chamber, a dosimetry module is available to cover a 7 decade range. When ordering, specify input connector and the maximum dose or dose rate to be measured and the calibration factor of the ionization chamber. These values and units will determine the module components and calibration adjustment so that the electrometer displays directly in the dosimetry units required
FEEDBACK MODULE RANGES: 7 decades from resolution digit to full scale

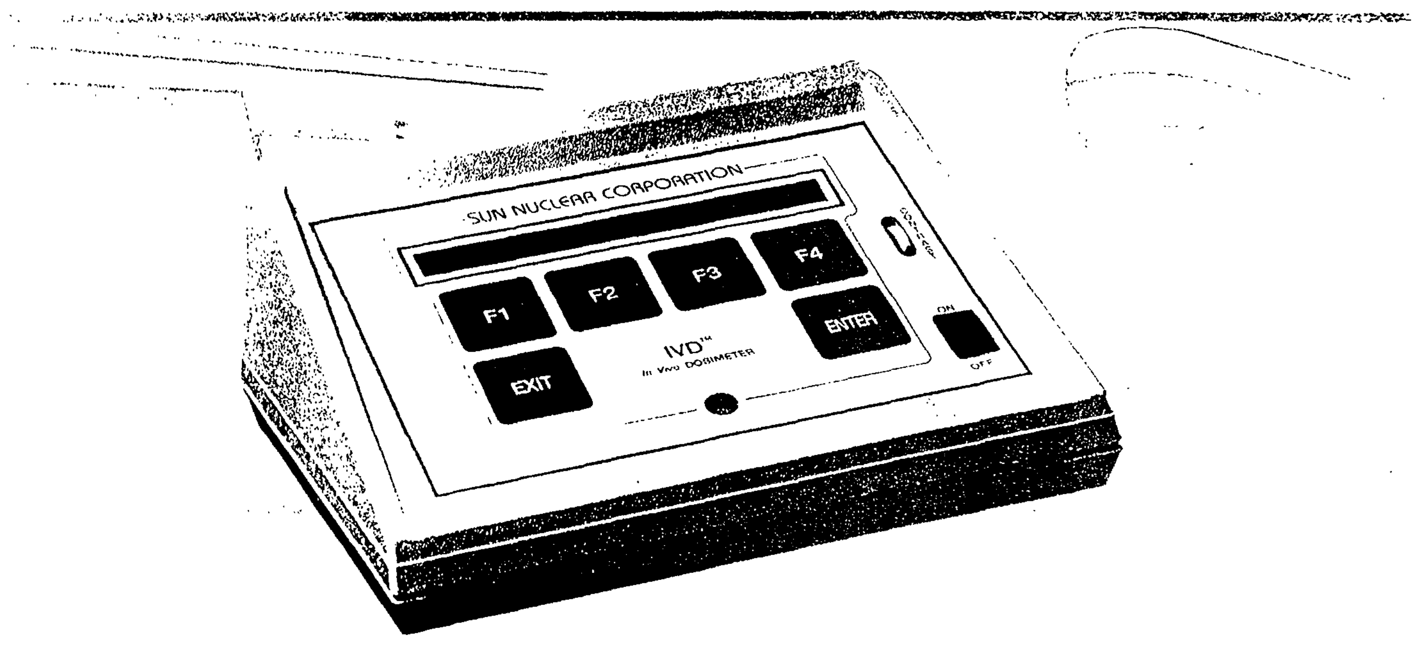
EXAMPLES:	RANGES:		
Module Value	High	Medium	Low
200 nC	199.99 nC	19.999 nC	1.9999 nC
2000 pA	1999.9 pA	199.99 pA	19.999 pA
2000 cGy	1999.9 cGy	199.99 cGy	19.999 c
20,000 mR/h	19999 mR/h	1999.9 mR/h	199.99

MODULE CONNECTORS: Triax (female) - BNC or TNC
Coax (female) - BNC/Banana Jack
Custom - Specify style and gender
REAR PANEL CONNECTORS: Electrometer analog output, ± 2 volt, banana jack External Bias, ± 600 volt DC maximum, banana jack.

[redacted]

In Vivo DOSIMETER

IVD . . .Becoming the Standard of Care



• ACCURATE

- Special Electrometer Allows Physics Calibration with a Precision of 1% or Better.

• CONVENIENT

- Stores up to 20 Detector Configurations.
- Outputs in Rads or Centigrays.

• RELIABLE

- Designed for use with Diode Detectors.
- Automatic Offset Voltage Adjust.
- FDA Approved with 510K.

In Vivo DOSIMETER

Providing the highest quality of care at the lowest cost to the patient, is the challenge facing medicine today.

The IVD ***In Vivo Dosimetry*** system increases the quality of care in any institution. By monitoring actual radiation dose to the patient, both the patient and the care provider gain information that provides greater assurance that the treatment received is as close as possible to treatment prescribed. In addition, through regular implementation of the IVD system, the care provider can track and report the level of quality offered by the institution.

IVD is a compliment to Record and Verify systems. R & V will detect random errors during the course of patient treatment. However, R & V may actually propogate a systematic error. On the other hand, IVD will detect both random and systematic errors.

Often, implementation of a quality assurance program means increased cost. Implementation of the IVD system addresses this concern in two ways. First, the system is designed to impact the patient as minimally as possible. The standard patient treatment routine requires only minor variations to incorporate the use of the IVD system. Second, in the U.S.A., the use of ***In Vivo Dosimetry*** is an accepted practice under standard reimbursement programs; thereby, offering an opportunity for the institution to offset the initial cost while adding significantly to the standard of care offered the patients.

The IVD system employs solid-state diode detectors. These small rugged detectors make placement and removal a simple and easy operation. The IVD system is designed such that all setup is performed during off hours, so that once patient treatment has begun the system can be properly configured, for any given patient, in a matter of seconds. The results are available during and immediately following the treatment. Turn-around time is immediate, once a treatment is completed and the data recorded, the system is available for the next patient.

The IVD patient dosimetry system is a fast, accurate, cost-effective patient treatment verification solution for those institutions striving to increase the standard of patient care while controlling service cost.

SPECIFICATIONS: When used with SNC or Nuclear Associates Diode Detectors

DISPLAY RANGES:
0.1 to 999.9 R (cGy).
1 to 999 R/Min (cGy/Min).

DOSE PRECISION:
0.5% or 2 digits (whichever is greater) at rates of 10R/min or greater.

ACCELERATOR LIMITS:

Pulse Maximum	1.1R (cGy)
Avg. Rate Maximum	3000 R/min (cGy/min)

DETECTOR CHANNELS:
2 channels with Model 113000-2
4 channels with Model 113000-3

ELECTROMETER INPUT:

Measured Current	1pA to 50nA, negative
Offset Bias	3 microvolt, Auto-Zero
Series Impedance	0 Ohm

CALIBRATION:
Automatic calculation and storage of calibration factors (DOSE/CNT * 1000) with user entered DOSE value.

ALARM:
Audible tone for dose or dose rate; set independent on each channel.

DISPLAY:
Liquid crystal, 2 line x 40 character alpha numeric, with contrast adjust.

CONTROLS:
Menu operation with 4 function keys F1, F2, F3, F4 plus EXIT and ENTER.

MEMORY:
Calibration factors for 20 detector groups stored in EEprom. Last setup configuration including detector group, time constant, alarms, special correction factors stored in battery backed-up RAM.

CLOCK:
Real-time battery backed-up clock for time stamping printout.

PRINTING:
IR LED port for Hewlett Packard 82240A Infrared Printer.
Centronics port for most parallel printers.

DIMENSIONS:
9.5" x 8" x 4" (24.1 cm x 20.3 cm x 10.2 cm)

WEIGHT:
5.5 Pounds (2.5 kg)

POWER:
External power supply, meets UL 544 (Medical and Dental Equipment) UL file E107077.
Input: 90 to 130 VAC, 50/60 Hz, 10W
Output: 20 VAC, 25 A

ACCESSORIES:

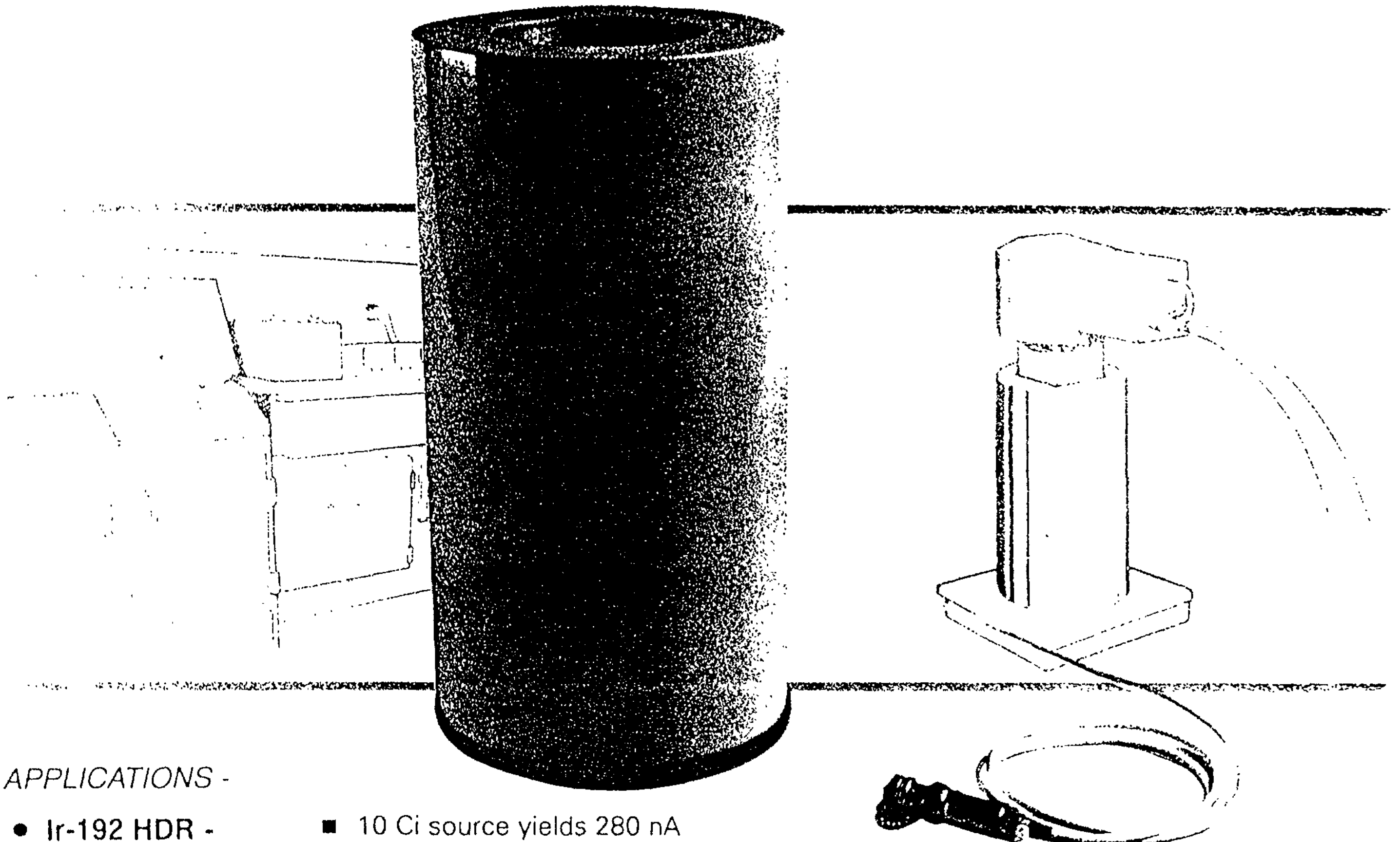
ISORAD Photon Detector 1-4MV	Part No. 114200-0
ISORAD Photon Detector 6-12MV	Part No. 114300-0
ISORAD Photon Detector 15-25MV	Part No. 114400-0
Electron Detector	Part No. 114000-0
Energy Compensated Detector	Part No 114100-0
Extension Cable (10 Meter)	Part No 114045-0
HP 82240A Infrared Printer	Part No 860084
Paper for HP printer (HP82175A)	Part No. 860083

[redacted]

RE-ENTRANT CHAMBER

HDR & LDR

"For all Brachytherapy source measurements"



APPLICATIONS -

- **Ir-192 HDR -**
  - 10 Ci source yields 280 nA
  - Pure Ar gas assures high collection efficiency
  - Stable response of sealed chamber
- **I-125 Seed -**
  - 0.5 mCi source yields 20 pA
  - Pure Ar gas provides enhanced response at low gamma energies
- **LDR Sources -**
  - Measures source activities as low as 0.1 mCi of Pd-103, I-125, Cs-137, Ir-192, Au-198, and Am-241

FEATURES -

- **STABLE -**
  - Hermetic seal with positive pressure argon fill gas provides unique response
  - No air density correction required
- **"SWEET SPOT" -**
  - Variation in axial response along 35 to 45 mm "sweet spot" is ± 0.5%
  - Flat response, ± 0.1%, is typically 20 mm long

RE-ENTRANT CHAMBER

The **SNC Model 1008** is a well type re-entrant ionization chamber designed for application to brachytherapy source strength measurement.

The design philosophy behind the **1008** considered the problems associated with the large thermal mass of re-entrant chambers, the electron contamination in beta emitting isotopes, the geometrical source placement errors along the axis, and the wide range of source strengths and gamma energies associated with brachytherapy.

The **Model 1008** chamber is hermetically sealed, therefore there is no air density correction requirement. All other re-entrant chambers are vented and therefore require a temperature measurement of the chamber gas which can be difficult due to the long thermal time constant resulting from the large thermal mass.

The aluminum wall of the **Model 1008** chamber well is 570 mg/cm², which absorbs all betas from Ir-192, Cs-137, and Au-198. Therefore, there is no signal contribution from electron contamination. Also, beta absorbtion can heat the chamber gas when high activity HDR sources are being measured. In a vented chamber, this is a problem. The **Model 1008** is sealed, therefore there is no heating effect.

The axial response of the **Model 1008** chamber provides the longest "sweet spot" of any brachytherapy re-entrant chamber due to its unique electrode design. Along the axis, the electrode is cylindrical. Then at the bottom, there is an electrode gap which provides additional chamber sensitivity as the source approaches the bottom. This provides a very flat axial response curve in the "sweet spot" instead of the traditional "parabolic" shape of the simple cylindrical geometries.

The fill gas of the **Model 1008** chamber is pure argon at an absolute pressure of 23.5 psi, which provides three distinct benefits. First, through photoelectric absorption, argon enhances the response at low photon energies emitted from isotopes such as I-125 and Pd-103. Second, because of its low electron attachment coefficient, argon provides a higher ion collection efficiency than air, making it more suitable for 10 Ci HDR Ir-192 source measurement. Third, the positive pressure provides long term constancy measurements with the ability to verify the chamber stability, without the influence of temperature/pressure corrections.

The **Model 1008** is fully guarded into the chamber, and is equipped with a 1.5 meter low noise triaxial signal cable, terminated with a triaxial bayonet connector.

Application accessories to the **Model 1008** for positioning and holding the source include:

- Aluminum catheter clamp which gently compresses a rubber o-ring around the catheter to give a friction lock.
- Three source holders for tubes, seeds, and ribbons

SPECIFICATIONS: (Subject to change without notice)

RADIATION DETECTED:

Gamma above 20 keV, Beta above 1200 keV

AXIAL RESPONSE VARIATION:

"Sweet Spot" defined as ± 0.5%
Nominal "Sweet Spot" length is 40mm ± 5
Center located between 36 and 46 mm from bottom of well
Nominal 20 mm length for ± 0.1% response variation.

NUCLIDE/PKG	NOMINAL RESPONSE nA/Ci
I-125/6711	38.0
I-125/6702	46.2
Cs-137/Tube	18.6
Ir-192/LDR	30.0
Ir-192/HDR	28.7

ION COLLECTION EFFICIENCY:

A_{ion} > 0.998 with 10 Ci of Ir-192.

ACTIVE VOLUME:

1.2 liter

IMPEDANCE:

Guard to Collector > 10^{15} ohm

MAXIMUM BIAS:

Guard to HV Electrode: 600 V

CABLE:

1.5 m low noise triax, terminated with bayonet TRIAX

CAPACITANCE:

100 pF

TEMPERATURE RANGE:

0° to 50° C

LEAKAGE CURRENT:

Guard to Collector, < 3 fA

WELL INSERT ALIGNMENT:

Two keyholes in chamber top

CONSTRUCTION:

Fill gas: 23.5 psi Argon, absolute pressure, 99.997% pure (Note, pressure is below DOT specifications for a pressure vessel; 1985 DOT 49 CFR 173.300 (a))
Well: 6063-T6 Aluminum, 0.211 cm wall (0.083" ± .012")
Collector: 5052-H32 Aluminum, 0.081 cm wall (0.032")
Electrode Separation: Well to Collector = 1 cm
Collector to Body = 1 cm

CHAMBER SIZE:

12.7 cm diameter by 25.4 cm high

WELL OPENING:

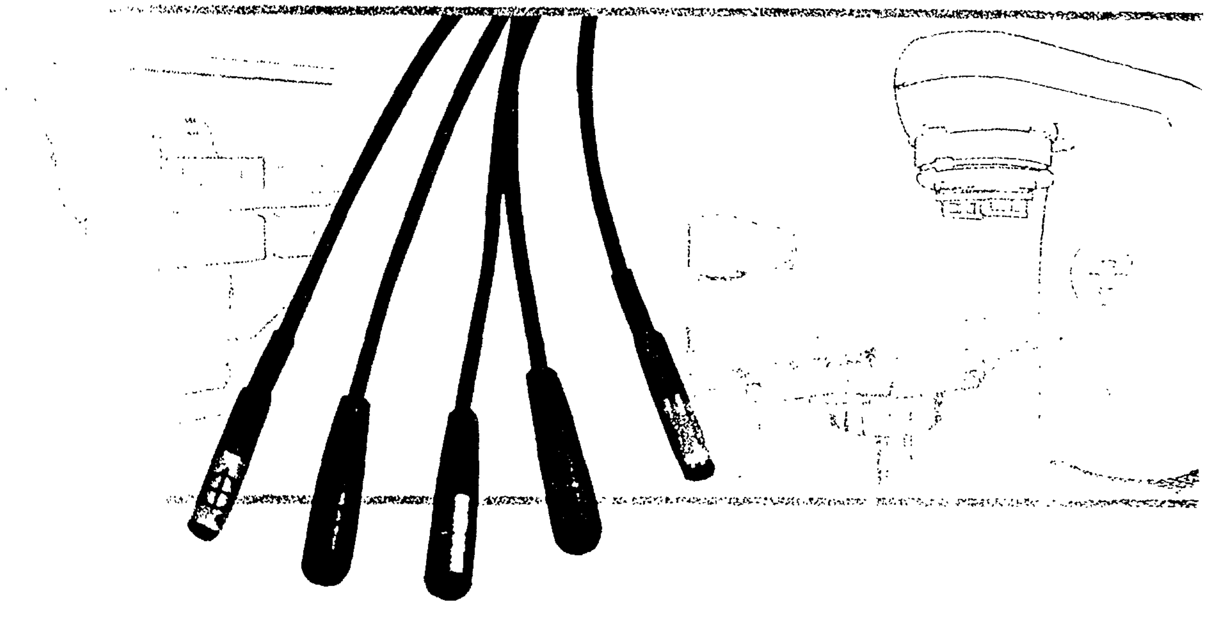
7.2 cm diameter by 16.7 cm deep

WEIGHT:

3 kg

ISORAD™ DETECTORS

Solid State Diodes for In-Vivo Dosimetry



- **SAFE FOR PATIENT MONITORING**
  - Requires no bias voltage
  - Minimal thermal effects
  - Rugged construction
- **EASY, QUICK SETUP**
  - Build up included for low, medium, and high xray energies
  - Color coded by energy
  - Real time readout - no processing
- **STABLE CALIBRATION**
  - Radiation damage effects minimized for all detector ranges
  - Very low temperature coefficient
  - Isotropic directional response

ISORAD™ Diode Detectors

The **Isorad Diode Detector** generates charge resulting from ionization occuring in and around the vicinity of the depletion region of the diode. When connected to the input of an electrometer, the collected charge serves as measurement of the radiation dose. This dosimetry technique has been well documented in the literature (1, 2, 3, 4, & 5).
The **Isorad Detectors** are safe for patient contact because there is no detector bias voltage required. These detectors are very easy to use with patients because there are no special handling procedures required.
The molded epoxy construction makes them rugged; the integral buildup for equillibrium response requires no additional buildup; the color coding by energy range makes them easy to identify. Furthermore, the measured dose is immediately available at the end of the treatment allowing the actual setup to be evaluated for errors.
Historically, diodes have been reported to be sensitive to temperature and radiation damage effects. This is due to the dependence of the minority carrier diffusion length on temperature and lattice damage in the silicon. This concern has been minimized in the **Isorad Detectors** through use of a proprietary n-type silicon.
Further to the improvements in diode measurements, instrumentation has been developed by **SUN NUCLEAR** which enables the highest degree of precision and stability that can be achieved with diodes. At the heart of this instrumentation (IVD and PC Rainbow) is an input circuit designed specifically for diode measurement of the pulsed beams used in radiation therapy. This circuit has a low leakage current and an input offset voltage of less than 5 microvolts which is required for minimum drift and maximum stability.

(1) P. Lee, etal, *"A Feasable Patient Dosimetry QA Program with a Commercial Diode System"*, Presented at the 1993 Annual AAPM (Z4), Med. Phys. 20, 912, 1993
(2) F. Kader, etal, *"Reduction In Sensitivity Variation of n-type Silicon Diode Detectors by Electron Pre-Irradiation"*, Presented at the 1993 annual AAPM (L28), Med. Phys. 20, 888, 1993.
(3) L. Gray, *"Properties of a Diode Dosemeter for Radiotherapy"*, Proceedings of the 4th Intl Conference on Medical Physics. 1976
(4) L.D. Gager, A.E. Wright, and P.R. Almond, *"Silicon Diode Detectors Used In Radiological Physics Measurements"* Parts I and II, Med Phys. 4, 494-502, 1977
(5) L.R. Wendell, B.J. Maddox, K.R. Kase, *"Daily Check Instrument for Photon and Electron Beam Quality Assurance of Medical Linacs"*, Med. Phys., 12, 462-465, 1985

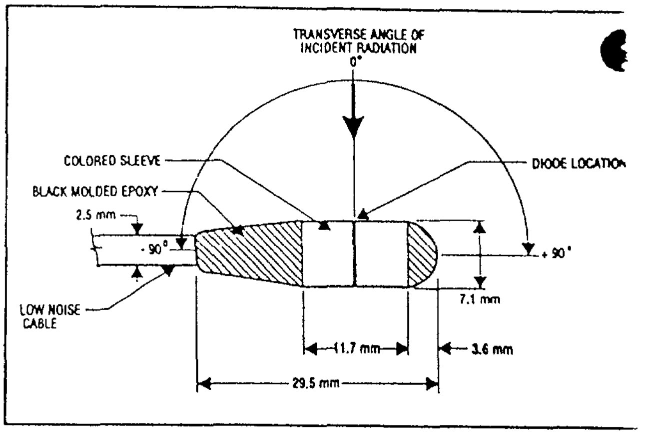


Fig. 1. ISORAD DETECTOR W/ TRANSVERSE DIRECTION ILLUSTRATE

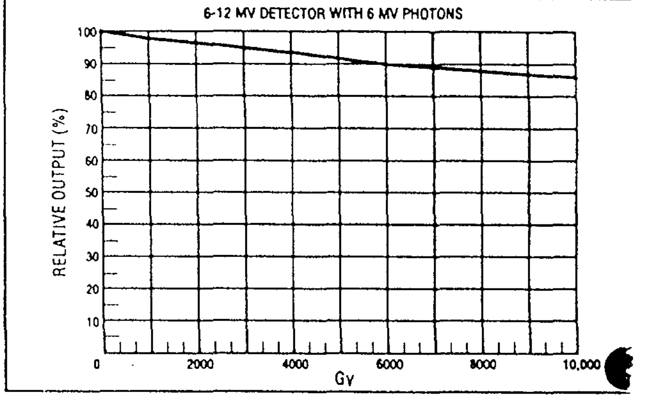


Fig. 2. ISORAD DETECTOR RESPONSE VERSUS RADIATION DAMAG

SPECIFICATIONS: (Subject to change without notice)

RESPONSE: Nominal 1 nC/R

MATERIAL: Special n-type silicon

CONSTRUCTION: Plane of silicon die mounted perpendicular to cable axis. Material build up around the die from the inside out consists of:

Silicon Oxide (0.169 g/cm²) + 330 Brass (0.303 g/cm²) + supplemental build up (See below) + Aluminum ID band (0.097 g/cm²).
Not waterproof.
Not recommended for intracavity measurements.

SENSITIVE GEOMETRY: Volume, nominal 0.30 mm³
Junction thickness, 0.075 mm
Junction area , 4.2 mm²

CABLE LENGTH: - output, 3 meter
\+ output, 10 meter
Special lengths available

ELECTROMETER RECOMMENDATION: Input offset voltage < 5µv
Series input resistance < 1 KΩ
Input leakage current < 0.1 pA

PHOTON ENERGY RANGES

	1-4 MV	6-12 MV	15-25 MV
Supplemental Buildup	Aluminum, 0.304 g/cm²	330 Brass, 0.965 g/cm²	Tungsten 2.18 g/cm²
Total Buildup	0.873 g/cm²	1.534 g/cm²	2 75 g/cm²
Transverse Response Fig. 1			
95% to 100%	-56° to +83°	-70° to +90°	-82° to +90°
90% to 95%	-73° to -56°; +83° to +90°	-90° to -70°	-90° to -82°
80% to 90%	-90° to -73°	N/A	N/A
Axial Response			
99.5% to 100%	0° to 360°	0° to 360°	0° to 360°
Radiation Damage: Response Change	-0.0014%/Gy	-0.0014%/Gy	-0.02% /Gy (2)
Temperature Coefficient: Typical	+0.1%/ °C	+0 1%/ °C	+0.16%/ °C
Sleeve Color:	Blue	Gold	Red
Part Number (-) Negative Output	114200-0	114300-0	114400-0
(+) Positive Output	114200-1	114300-1	114400-1

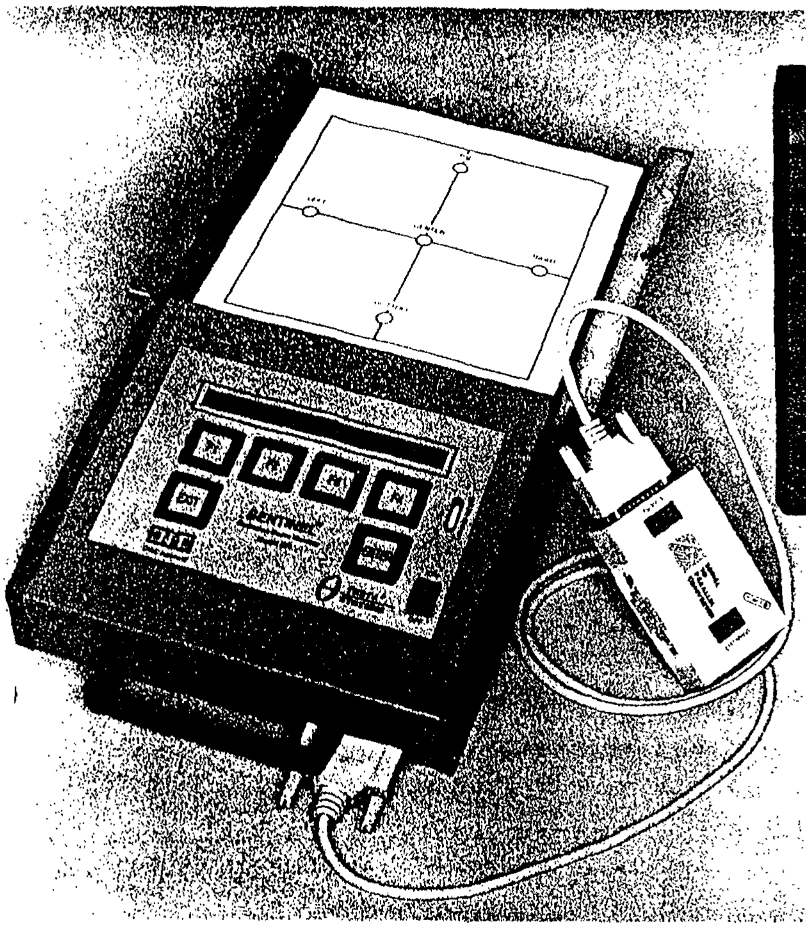
NOW YOU CAN GET ACCURATE, INSTANTANEOUS RADIATION DOSE MEASUREMENTS DURING PATIENT TREATMENT. . .UNDER COMPUTER CONTROL

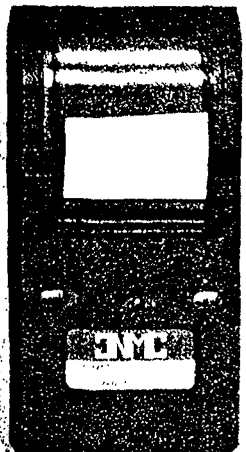
PC-RAINBOW™

NEW INNOVATIVE

THERAPY BEAM MONITORS

SENTINEL™ 629 AND BEAM SENTRY 104 OR 114



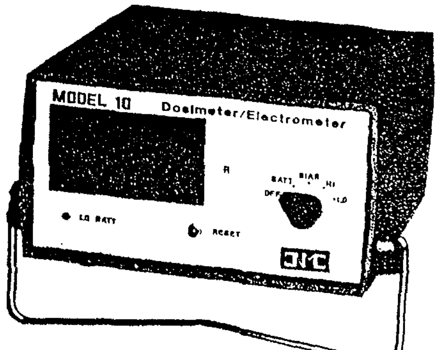


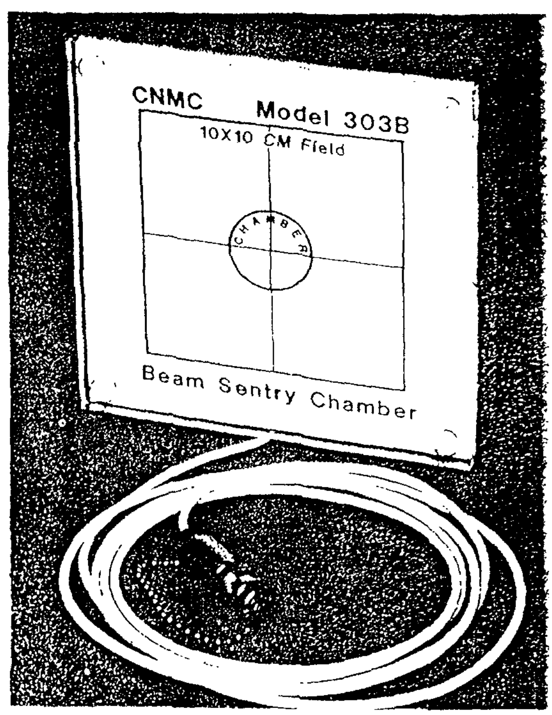
SENTINEL™ 629:
- 5 ion chambers, 1cm^3
- Direct reading or Ratio Output
- Stored calibrations for 20 energies
- Temperature-Pressure correction
- Automatically averages readings and calculates symmetry and flatness
- User selected alarm points
- Interfaces to printer, computer
- Gantry-collimator attachment device

OPTIONS:
- Remote readout/controller
- Various printers/computers
- Serial-to-parallel adaptor
- SuperCalc software

MODEL 104 BEAM SENTRY (10/303B)
- 3cm^3 parallel plate ion chamber suitable for accelerator, cobalt, superficial, diagnostic and mammography
- Acrylic phantom with removable buildup plates
- BNC or TNC triaxial connectors
- 4½ digit LCD, 2-range display
- Units: nC, cGy or R
- Battery operation/bias

MODEL 114 BEAM SENTRY (11/303B)
- As above, but with rechargeable battery operation, variable electronic bias and rate mode.





SENTINEL™

Designed for daily constancy/symmetry checks of radiation puts from high energy accelerators and cobalt machines. High ility, ease of use, and versatility are the prime objectives in the ntinel design. The instrument is microprocessor based which vides the user a simple, but accurate daily device. This is ıanced further by the fact that the instrument remembers your up, prompts the operator along predetermined protocol and res data for later printing or downloading to a computer at a re convenient time.

The physical design also is unique, in that rails are provided ıllow the Sentinel to slide directly into Varian style block tray port. That provides radiation output as a function of gantry gle. The one-piece construction eliminates the need for a stly, troublesome ion chamber interconnect cable.

Optional remote control/readout unit completely duplicates the ıel function of the Sentinel and permits operation from outside the treatment room.

ᴾECIFICATIONS:

odel 629

curacy:	Within 1% for Co-60, absolute
›eatability:	Within 0.5% for all high energy photons
:ectors:	One central ion chamber, four chambers spaced at 8cm off central axis on the X-Y axes; imbedded in 1/2" acrylic
amber size:	1cc; 1cm dia x 1.27cm deep, unsealed
ldup:	0.5g/cm²; 1.5mm Al & 0.5mm polycarbonate; additional buildup may be achieved by using standard 25 x 25 cm slabs
ıge:	0.1 to 999.9 rad
e limitation:	0.5 to 999.9R/min
play:	Two line, 40 character alphanumeric LCD, displays data, instrument status and functions
ıtrols:	Four soft keys correspond to displayed function prompts, one enter and one exit key
ibration memory:	Up to 20 beam calibrations stored,including calibration #, machine ID, SSD, MV, MU, gantry angle, alarm limit, number of exposures, temperature, pressure, time and date
ıit alarm:	User selected low and high deviation limit alarms
ta memory:	Up to 180 measurements stored for printing or downloading to a computer
asurement data:	Absolute, ratio, average, percent of calibration, flatness and symmetry change
ta links:	RS-232 for computer, serial printer, and remote unit. Infrared sender for H-P printer
ver:	Internal rechargable battery, 120VAC UL listed adaptor provided.
e:	45.7 x 26.7 x 8.9 cm (18 x 10.5 x 3.5 in)
ight:	7.72 kg (17 lb)

PTIONS:

›del 629R	Remote control/display unit, complete with 50 foot interface cable
›del HP-IR	HP 82240B, IR-link thermal 24 column printer, including 120VAC adaptor
›del S/P ADAP	Serial to parallel adaptor
›del LX-810S	Serial/parallel dot matrix printer, including printer cable

SENTINEL II

The most significant feature of the Sentinel II is the upgradability option. In addition to being a unique programmable five ion chamber daily beam output and symmetry monitor, it may also be economically upgraded to perform a dual function as a Patient Dose Verification Monitor. As such, the Sentinel II does not rest idle after the daily beam output checks are done, it can use the same microprocessor power and features to process patient exposure data from up to five diode detectors.

The main components of the Sentinel II are:

- **55I** ion chamber module contains 5 sealed ion chambers that require no air density corrections. One ion chamber is located in the center of the 20 x 20cm field and four ion chambers are spaced at 8cm off central axis on the X-Y axes, imbedded in 1/2" acrylic. A chamber hole is provided to fit a Farmer type ion chamber to allow cross-calibration of center ion chamber. Two metal rails along two sides allow convenient mounting directly to a shadow tray whenever it is desired to perform output measurements at various gantry angles. The two rails are spaced to accommodate standard 25cm² acrylic buildup material. The ion chamber module contains no electronics and every effort has been made to thoroughly shield the ion chamber signals from the effects of RF.
- **55E** electrometer module is normally attached to the 55I ion chamber module. It contains five-channel electrometer and digitizes data before sending it via a fiber optics cable to the readout/control module which is meant to be located outside the treatment room at the control panel. The electrometer module may be removed from the ion chamber module for the purpose of attaching optional five-channel diode module, transforming it into a Patient Dose Verification Monitor.
- **55CU** control/display module provides convenience of reading data and operating the Sentinel II from a remote location outside of treatment room. It contains the microproccessor, battery backed up memory, a two line alphanumeric display, a user friendly six key multifunction control panel, and outputs for parallel Centronics printer, infrared-link HP tape printer and RS-232 port for downloading data to a IBM compatible computer.
- **55DM** optional 5-channel diode detector input module serves to expand the basic capability of Sentinel II. It attaches to the 55E electrometer module and accommodates the outputs of up to five diode detectors, thus significantly increasing the usefulness of the Sentinel II. The patient dose data can then be similarly processed, stored, printed and downloaded to a computer.
- **Diode Detectors** are available to satisfy a wide range of photon and electron energies. Representing state-of-the-art in diode dosimetry, diode detectors deliver high sensitivity and stability through the use of integral filters and build-up shields. Sophisticated mountings, noble metal doping materials and unique cylindrical design minimizes temperature effects caused by patient heat transfer during treatment and provide excellent geometry.

OPTIONS:

55DM	Diode module and firmware to allow interface with up to five diode detectors for patient dose monitoring
55SW	Software to provide two-way PC interface for calibration and data management for up to five diodes
30-481-8000	Diode detectors, 1 - 4 MV photons
30-487-8000	Diode detectors, 6 -12 MV photons
30-488-8000	Diode detectors, 15-25 MV photons
30-495-8000	Diode detectors, 6 -25 MV electrons

INSTRUCTION MANUAL

for

DOSE-DOSERATE METER

TYPE 2620

X86

NE TECHNOLOGY LIMITED

3.0 SPECIFICATIONS

3.1 DOSE/DOSERATE MEASUREMENTS

3.1.1 Range Full Scales:

Measurement Mode	Low Range	High Range
Charge	19.999 nC	199.99 nC
Dose	199.99 *	1999.9 *
Current	199.99 pA	1999.9 pA
Doserate	199.99 */min,	1999.9 */min

* cGy, rad or R as set by position of Legend Panel.

3.1.2 Resolution: 0.005 % of Full Scale

3.1.3 Performance:

Measurement Mode	Calibration Accuracy	Linearity	Long term Stability	Temperature Coefficient
Charge	±0.5 %	±0.1 % F.S.	±0.5 % p.a.	±0.05 %/°C
Dose	±0.5 % ±A	±0.1 % F.S.	±0.5 % p.a.	±0.05 %/°C
Current	±1.0 %	±0.1 % F.S.	±1.0 % p.a.	±0.05 %/°C
Doserate	±1.0 % ±A	±0.1 % F.S.	±1.0 % p.a.	±0.05 %/°C

Where A is the Calibration Uncertainty quoted for the Chamber Calibration.

3.1.4 Leakage current: $< \pm 3 \times 10^{-14}$ A

3.1.5 Time constant: 0.15 s on the Low Current and Doserate Ranges
0.05 s on the High Current and Doserate Ranges

3.2 ELAPSED TIME MEASUREMENT (only applies to 2620A with Timer)

3.2.1 Timer range Full Scale: 1999.9 s

3.2.2 Timer accuracy: ±0.02% ±0.1 s at +25° C

3.2.3 Timer temperature coeff: ±0.02 %/°C

3.2.4 Timer resolution: 0.1 s

3.3 POLARISING VOLTAGE SUPPLY

3.3.1	Selectable HV values:	±360 V, ±180 V, ±90 V, ±45 V, ±22.5 V
3.3.2	HV supply accuracy:	±1 V
3.3.3	HV ratio accuracy:	±0.5%
3.3.4	HV measurement accuracy:	±1 V
3.3.5	HV output temperature coeff:	±200 ppm/°C
3.3.6	HV output impedance:	>1 MΩ
3.3.7	Max energy discharge:	<2 mJ

3.4 INPUT CONNECTOR FOR CHAMBER: Fixed Triaxial TNC Socket

3.5 POWER SUPPLY REQUIREMENTS

3.5.1	Mains type:	Single phase A.C. with an external protective earthing system
3.5.2	Nominal voltage range:	100 - 120 V ±10% 200 - 240 V ±10%
3.5.3	Acceptable frequency range:	48 to 63 Hz
3.5.4	Power rating:	10 VA

3.6 TEMPERATURE RANGE

3.6.1	Operation:	+10° C to +40° C
3.6.2	Storage:	-15° C to +50° C

3.7 MECHANICAL SPECIFICATION

3.7.1	Dimensions:	Width:	320 mm
		Depth:	285 mm
		Height:	145 mm
3.7.2	Weight:		4.5 kg

3.7.3 **Possible angles of Front Panel**
(relative to a horizontal bench):

- resting on 4 Rubber Feet on Base:	90°
- resting on Handle:	88°, 78°, 70°*
- resting on 4 Rubber Feet on Rear Panel:	0°

* 70° is the recommended angle for bench use (see Figure 1).

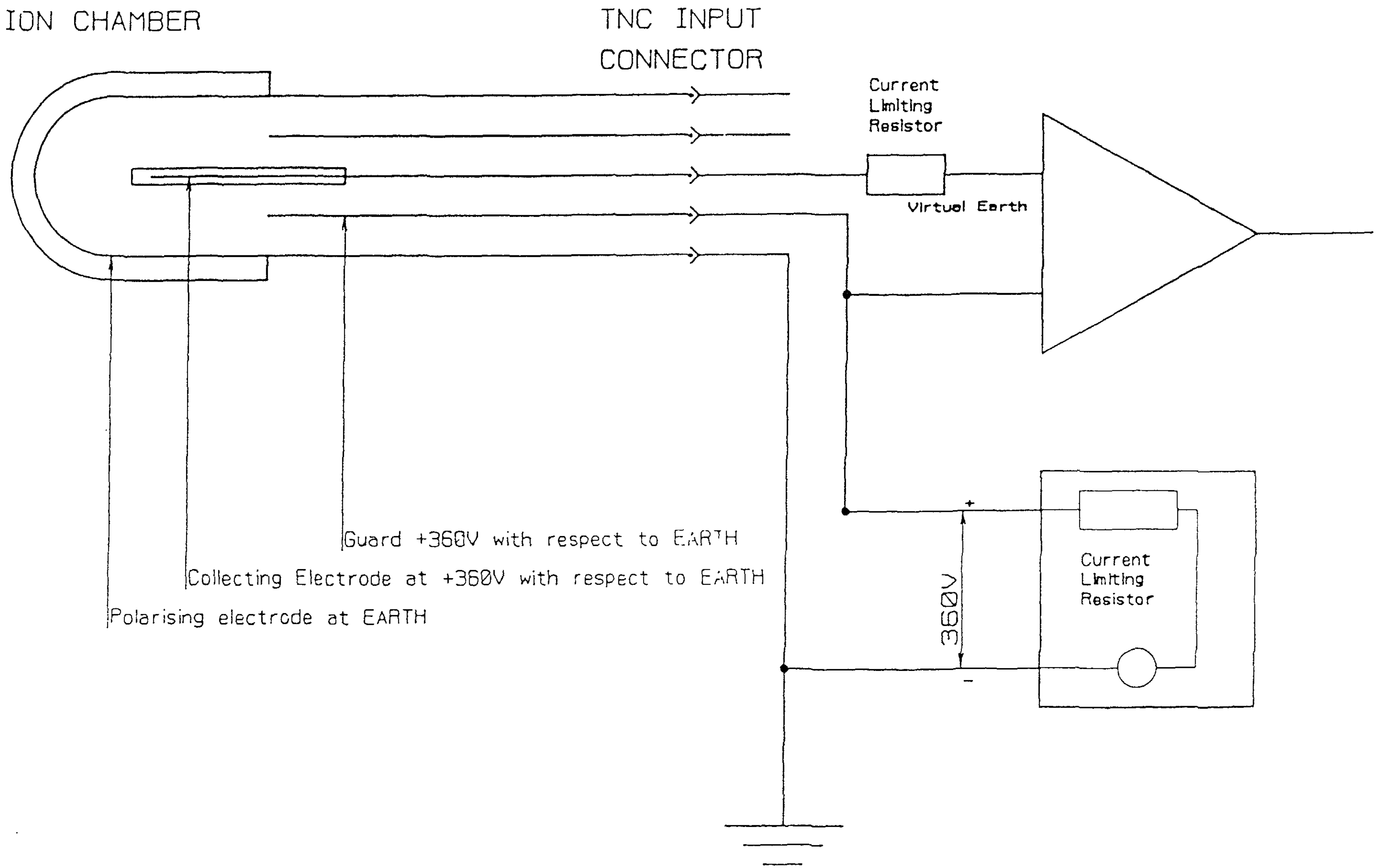


FIGURE 3 - EARTHING OF 2620 AND CHAMBER (shown for HV polarity set to -ve)

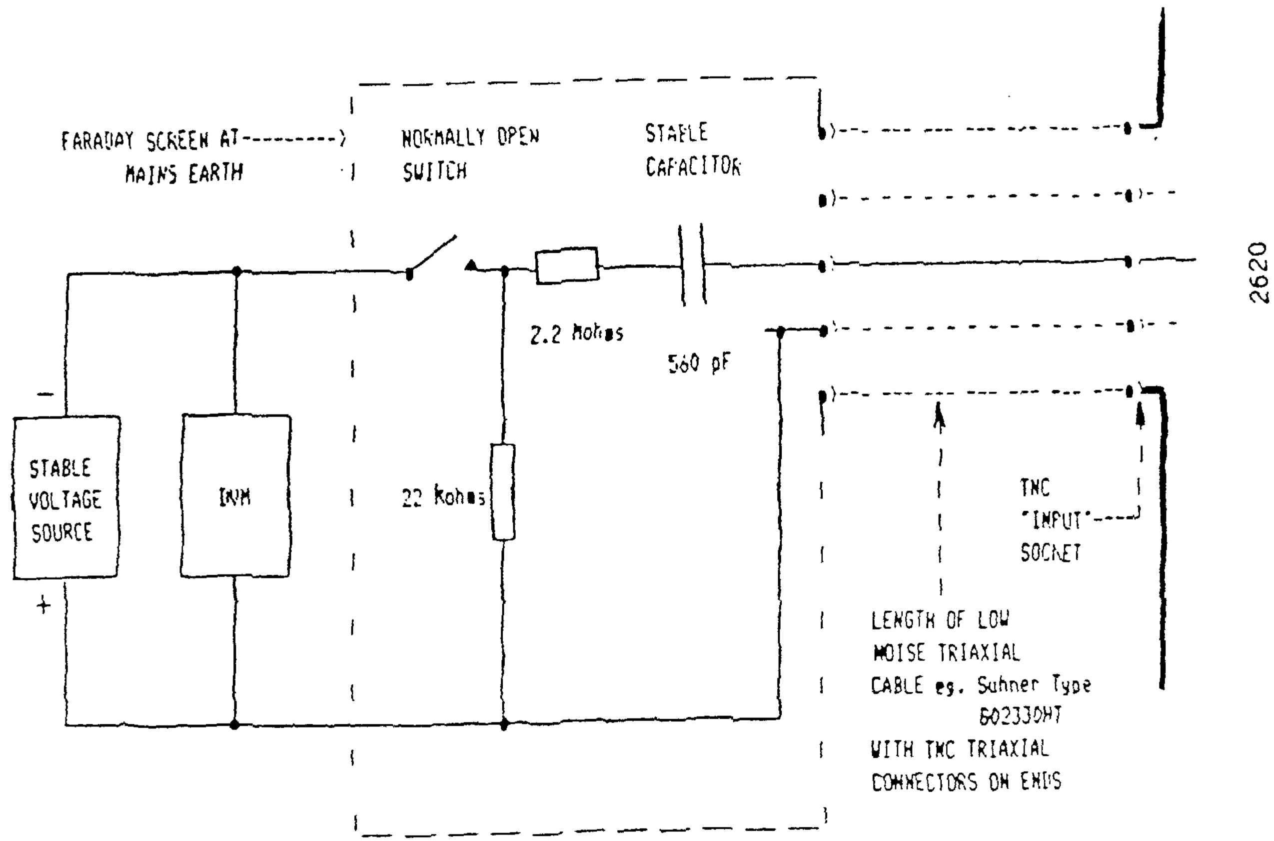


FIGURE 7 - CONNECTION OF CHARGE CALIBRATION EQUIPMENT TO 2620

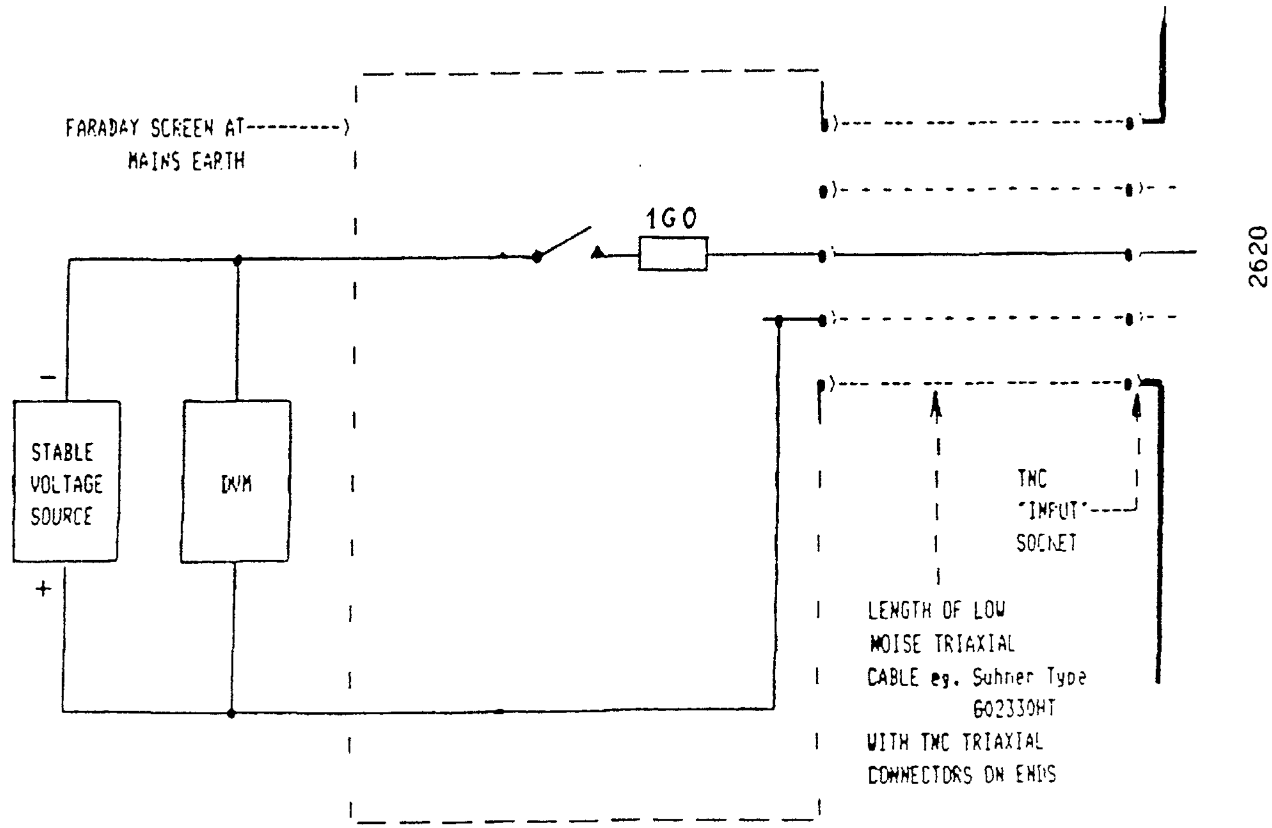


FIGURE 8 - CONNECTION OF CURRENT CALIBRATION EQUIPMENT TO 2620

KEITHLEY INSTRUMENTS

Model 614 Electrometer Instruction Manual

Contains Operating and Servicing Information

Publication Date: July 1991
Document Number: 31896 Rev. D

SPECIFICATIONS

ιGE

E	RESOLUTION	ACCURACY (1 YEAR) 18°-28°C ±(%rdg + digits)	TEMPERATURE COEFFICIENT 0°-18°C & 28°-35°C ±(%rdg + digits)/°C
	10 μV	0.08% + 2d*	0.005% + 2 d
	100 μV	0.08% + 1d	0.005% + 0.2d
	1mV	0.08% + 1d	0.005% + 0.1d

perly zeroed.

Greater than 60dB at 50Hz and 60Hz.

Greater than 120dB at DC, 50Hz and 60Hz.

IMPEDANCE: Greater than $5x10^{13}$ in parallel with 20pF.

IUM OVERLOAD: 350V peak.

꞉ENT

RESOLUTION	ACCURACY (1 YR.) 18°-28°C ±(%rdg + digits)	TEMPERATURE COEFFICIENT 0°-18°C & 28°-35°C ±(%rdg + digits)/°C	MAXIMUM SUPPRESSION
10fA	1.5% + 5d*	0.1 % + 1 d	± 20pA
100fA	1.5% + 3d	0.1 % + 0.3d	±200pA
1pA	1.5% + 1d	0.1 % + 0.3d	±200pA
10pA	0.5% + 2d	0.02% + 0.3d	± 20nA
100pA	0.5% + 1d	0.02% + 0.3d	±200nA
1nA	0.5% + 1d	0.02% + 0.3d	±200nA
10nA	0.3% + 2d	0.01% + 0.3d	± 20μA
100nA	0.3% + 1d	0.01% + 0.3d	±200μA
1μA	0.3% + 1d	0.01% + 0.3d	±200μA

rent suppress.

BIAS CURRENT: Less than 60fA at 23°C.

VOLTAGE BURDEN: Less than 200μV.

ɅP SETTLING TIME (to 1% of final value): pA, 0.6s. nA, 5ms. 2.5ms.

ǀ: pA and nA, 70dB. μA, 55dB. At 50Hz and 60Hz.

MUM OVERLOAD: pA and nA, 350V peak. μA, 75V peak.

STANCE

E	RESOLUTION	ACCURACY (1 YR.) 18°-28°C ±(%rdg + digits)	TEMPERATURE COEFFICIENT 0°-18°C & 28°-35°C ±(%rdg + digits)/°C	TEST CURRENT
)	1 Ω	0.5% + 2d	0.03% + 0.3d	100μA
)	10 Ω	0.5% + 2d	0.03% + 0.3d	100μA
)	100 Ω	0.5% + 2d	0.03% + 0.3d	10μA
)	1 kΩ	0.8% + 2d	0.04% + 0.3d	100nA
)	10 kΩ	0.8% + 2d	0.04% + 0.3d	100nA
)	100 kΩ	0.8% + 2d	0.04% + 0.3d	100nA
)	1MΩ	2.0% + 3d	0.12% + 0.3d	100pA
Ω	10MΩ	2.0% + 2d	0.12% + 0.3d	100pA
Ω	100MΩ	2.0% + 2d	0.12% + 0.3d	100pA

MUM OPEN CIRCUIT VOLTAGE: 32V DC.

MUM OVERLOAD: kΩ, 75V peak. MΩ, GΩ, 350V peak.

ꓥRGE

RANGE	RESOLUTION	ACCURACY (1 YEAR) 18°-28°C ±(%rdg + digits)
0.2nC	10fC	5% + 50d
2 nC	100fC	5% + 5d
20 nC	1pC	5% + 1d

JT BIAS CURRENT: Less than 60fA at 23°C.

ꓫIMUM OVERLOAD: 350V peak.

GENERAL

DISPLAY: Five LED digits with appropriate decimal point, polarity and overload indication.

CURRENT SUPPRESS: Active in Current mode; allows correction for input currents on any given range.

CONVERSION TIME: 400ms.

2V ANALOG OUTPUT: 2V out for full range input. Inverting in Voltage and Resistance modes. Output impedance: 10kΩ.

PREAMP OUTPUT: Provides a guard output for Voltage and Resistance measurements. Can be used as an inverting output or with external feedback in Current and Coulombs modes. Output impedance: 1kΩ.

MAXIMUM COMMON MODE VOLTAGE: 500V peak.

CONNECTORS: Input: Triax. **Output:** 5-way binding posts.

ENVIRONMENT: **Operating:** 0°C to 35°C up to 70% relative humidity. **Storage:** −25°C to +65°C.

POWER: Line or battery operated. 105-125V or 210-250V (switch selected), 90-110V available. 50-60Hz, 5VA typical; 18VA maximum during battery charge. 10 hour operation from full charge, 20 hours to recharge.

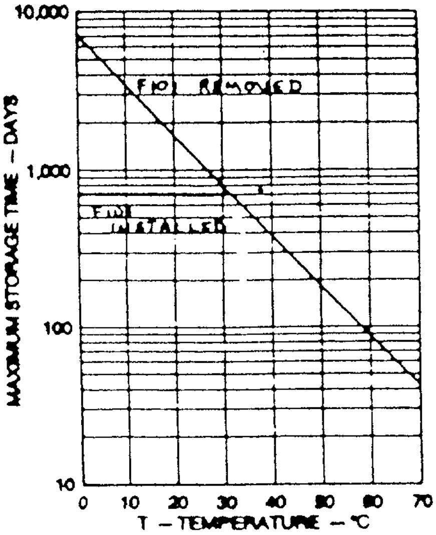
DIMENSIONS, WEIGHT: 127mm high × 216mm wide × 359mm deep (5" × 8½" × 14¹/₈"). Net weight 3.3kg (7.2 lbs.).

ACCESSORY SUPPLIED: Model 6011 Triaxial Input Cable.

ACCESSORIES AVAILABLE:
- Model 1019 Universal Rack Mounting Kit
- Model 6011 Input Cable
- Model 6102A Voltage Divider Probe (up to 200V with 614)
- Model 6103C Voltage Divider Probe (up to 20kV with 614)
- Model 6104 Test Shield
- Model 6105 Resistivity Chamber
- Model 6146 Triax Tee Adapter
- Model 6147 Triax to BNC Adapter
- Model 6167 Guarded Adapter
- Model 6301 Guarded Probe

Model 614 Specification Addenda

1. "When Properly Zeroed" refers to readjusting the Volts Zero pot after greater than 1°C change in ambient temperature or every 24 hours.
2. Normal mode rejection specification applies for signal and noise of less than full range.
3. "Preamp settling time to 1% of final value" assumes a step input from 0 to full range.
4. Overall specifications are valid for overload signals under 1kHz.
5. Model 614 storage time must be derated according to manufacturer's specification for the BA-35 Battery Pack at temperatures above 25°C.



Storage Characteristics

SECTION 5
THEORY OF OPERATION

INTRODUCTION

Model 614 Electrometer is a multifunction meter ble of detecting currents as low as 10^{-14}A, providing input impedance ($5 \times 10^{13}\Omega$) on Volts and measuring up 00GΩ with minimal error. To accomplish this, the Model ncludes a special preamplifier circuit which gives it the trometer characteristics. A second stage voltage lifier scales the preamplifier output so that the A/D cir- will receive 2V input for full range. Figure 5-1 shows an all block diagram for the Model 614.

5.2 INPUT PREAMPLIFIER

The Input Preamp is designed to provide high input impedance for the Volts and Resistance functions, and low input impedance (with 6×10^{-14}A input current) for the Current and Coulombs functions. Refer to Figure 5-2 for the basic circuit configurations provided for the different functions. The preamp becomes a high input impedance, unity-gain buffer amplifier in the Volts function. In the Resistance function, a boot-strapped voltage source in series with a range resistor drive a constant current through the

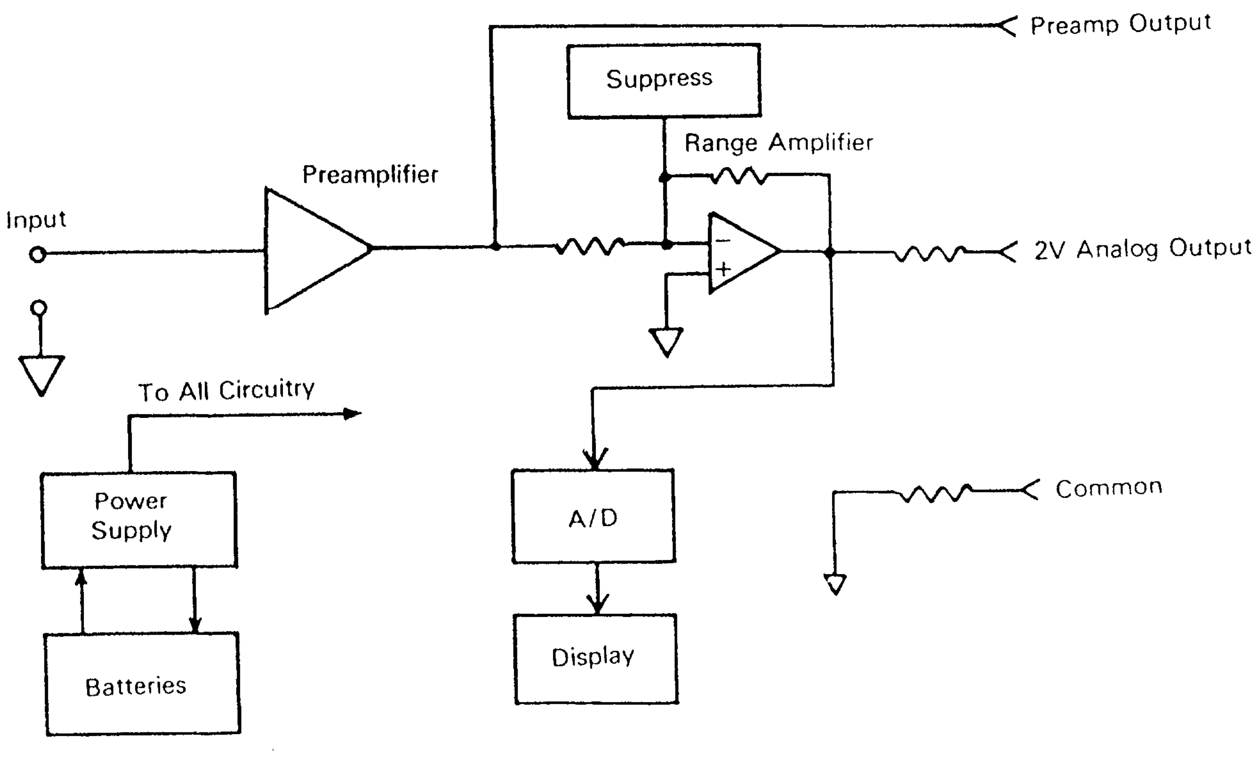


Figure 5-1. Model 614 Block Diagram

nknown. The voltage developed across the unknown esistance is proportional to its resistance. This voltage is esent at the output of the unity-gain buffer, and thus prodes an output voltage proportional to the resistance under est. In the Current (I) and Charge (nC) functions, the eamplifier is configured as a feedback current to voltage onverter. Feedback resistor R is selected by the front panel uttons labeled μA, nA and pA. Each configuration will now e considered.

.3 VOLTS

n the Volts function the Model 614 is configured as a high mpedance unity-gain buffer amplifier capable of measuring up to 20V with >5 x $10^{13}\Omega$ input impedance. Refer to Figure 5-3. The JFET pair Q104 is the sensitive input device. U102, Q101, Q102, Q104, CR101 and CR102; and associated components are configured as a high impedance buffer amplifier. CR101 and CR102 provide a constant current 1mA bias for VR101 and VR102. Q101 and Q102 buffer this voltage and supply drive for U101 and U102. R113, C107, and R112 provide input protection without sacrificing stability. C101, C102, and C106 provide unity-gain frequency compensation to the amplifier. Resistors R115 and R116 are a matched pair, providing 30μA bias to Q104. If the input FET pair is ever replaced, reinstall jumpers W101 and W102 and follow the procedure for nulling the input offset voltage. This procedure is outlined in Paragraph 6.4.2.

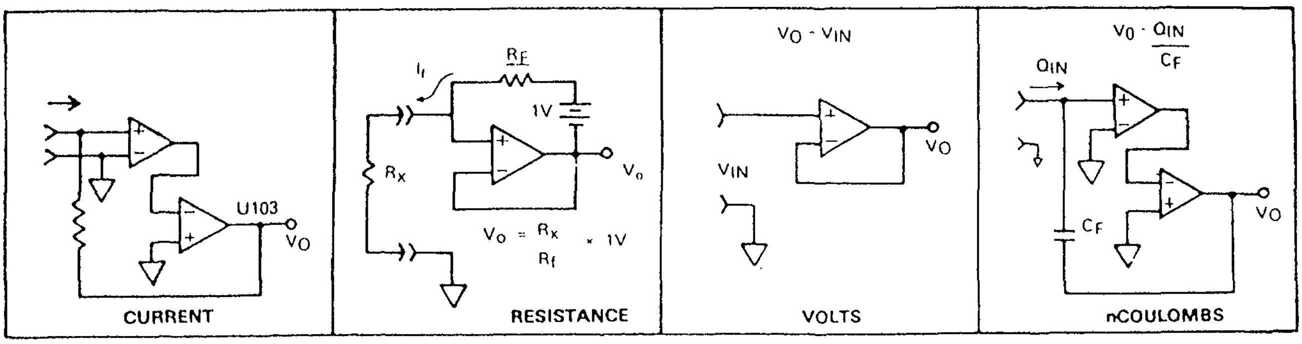


Figure 5-2. Basic Circuit Configurations

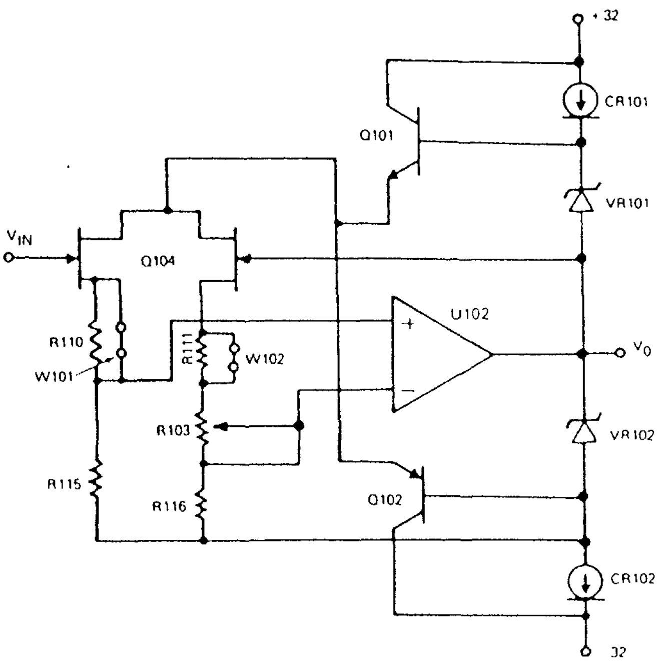


Figure 5-3. Volts Configuration

5.4 RESISTANCE

The Resistance function operates similar to the Volts function, except that a reference voltage of 1V is generated by U101, VR101, and associated components. Potentiometer R101 sets this voltage which can be measured between TP1 and TP2. Refer to Figure 5-4. R104, R105, C104, and C108 stabilize the reference.

The series feedback resistor is selected by the front panel buttons labeled kΩ, MΩ, GΩ. Table 5-1 summarizes this selection.

Table 5-1. Feedback Resistors

UNITS SELECTION	RELAY	R_{FB}	C_{FB}
kΩ	K103	R121, (R108 on 200Ω)	C112
MΩ	K102	R102,	C111
GΩ	K101	R117,	C109

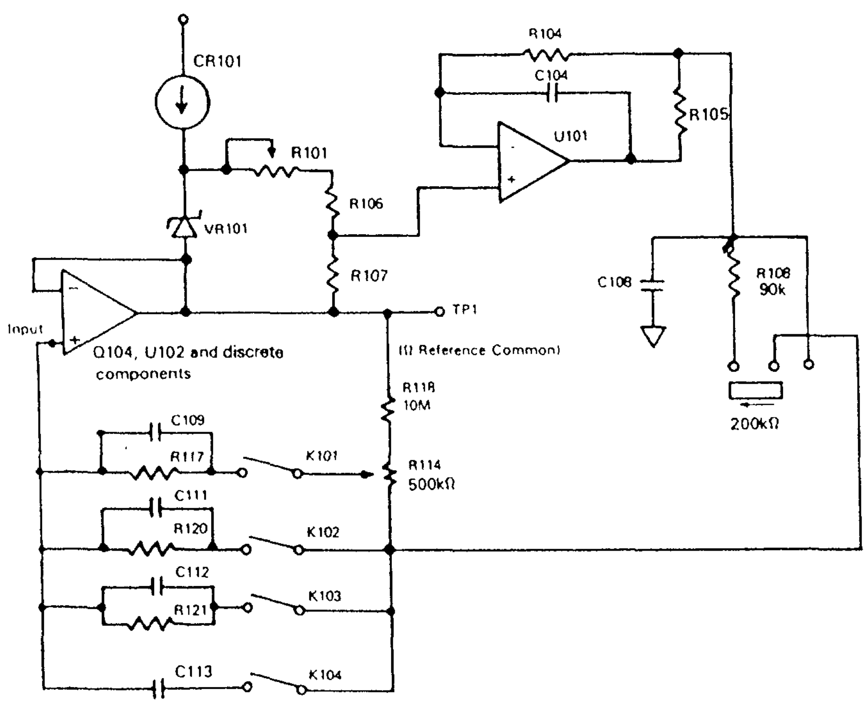


Figure 5-4. Resistance Configuration

Capacitors C109, C111, and C112 provide frequency stability to the feedback circuit.

No calibration is necessary for R120 and R121. However, R117 is a 9.8 x $10^9\Omega$ HI meg resistor requiring calibration. This is provided by R114. Resistors R114 and R113 form a voltage divider at the amplifier output which makes R117 "look" like its value is being calibrated.

NOTE

This calibration is done for the 2000pA range. Once it is set, the GΩ ranges are calibrated. It is not touched during Resistance calibration. Resitance calibration involves adjusting R101 and monitoring TP1 for 1.0000V $\pm 500\mu V$. See paragraph 6.4.3

For the 200kΩ range, it is necessary to switch R108 in series with the resistor R121. This keeps the compliance voltage across the unknown below 2V, thus limiting the power dissipation.

5.5 CURRENT AND CHARGE

When either the Current (I) or Charge (nC) function is selected, the input preamplifier configures itself as a current to voltage amplifier. Refer to Figure 5-5.

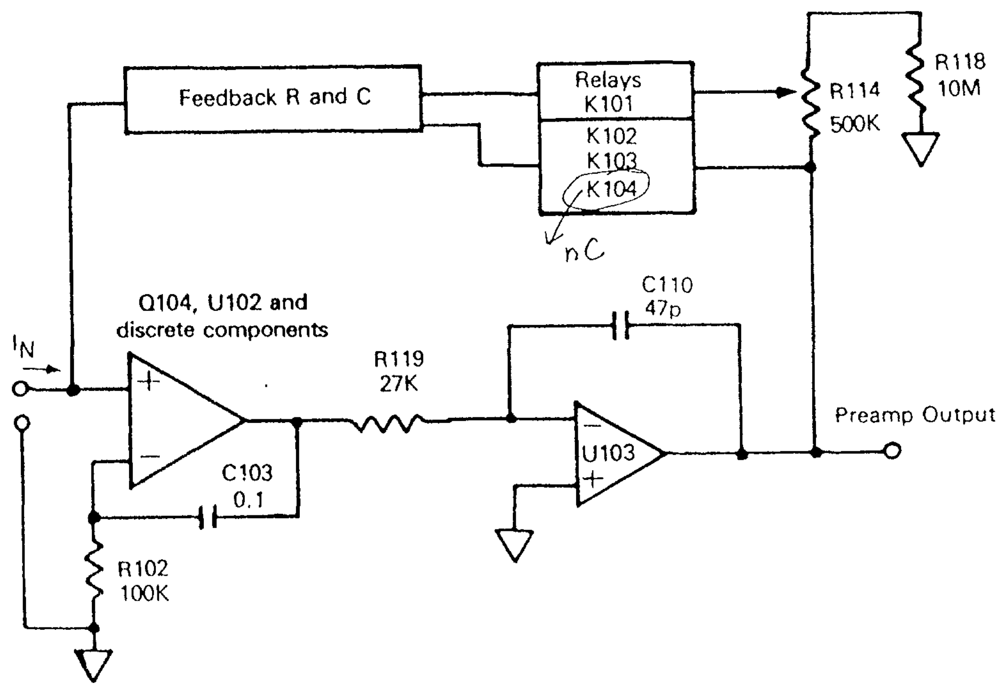


Figure 5-5. Model 614 Preamplifier Configured in Current or Coulombs

In this mode the output from the Volts input buffer is fed into U103 via R119 and C110. High voltage op amp U103 serves two purposes:

1. Provides ±20V swing necessary to cover all Current ranges.
2. Provides the inversion necessary for feedback current.

The supply voltages to U103 are regulated ±32V and are discussed in paragraph 5.8.3.

Since at DC U102 and U103 operate without local feedback, the DC loop gain exceeds 10^{10}. This means that the accuracy depends on the feedback resistor selected. To frequency compensate this circuit, multiple poles and zeroes are required. This compensation is provided by R102, C101, C103, R119, and C110.

Note that the composite current amplifier circuit behaves like an op amp with a single pole for frequencies above 10Hz.

The appropriate feedback element is selected by the μA, nA, pA, or nC buttons on the front panel. Table 5-2 is a list of the values selected.

Table 5-2. Feedback Elements

UNITS SELECTED	RELAY	ELEMENTS SELECTED
μA	K103	R121, C112
nA	K102	R120, C111
pA	K101	R117, C109
nC	K104	C113

Capacitors C109, C111, and C112 provide frequency compensation and cancel the effect of cable capacitance on the input. These capacitors also set the preamp settling time.

The only feedback resistor requiring calibration is R117. This resistor is calibrated by R114 on the 2000pA range.

The feedback relays K101 - K104 are low-leakage devices displaying > $10^{14}\Omega$ at environmental extremes.

5.6 ZERO CHECK

The Zero Check actuator is a mechanical spring, actuated by the ZERO CHECK button. when Zero Check is in, the input impedance of the instrument changes. For more detail, see Figure 2-1.

Resistor R113 prevents damage to the instrument during overload when Zero Check is operated. Resistors R112 prevents the use of the Zero Check function from damaging the input FETS.

5.7 RANGING CIRCUIT

The ranging circuit converts the output of the preamplifier into a ±2V output for a full range input. Refer to Figure 5-6. As seen, the circuit is a simple inverting amplifier with a gain of 10, 1, or 0.1. The gain is selected according to the range buttons on the front panel. The following table summarizes the gains selected.

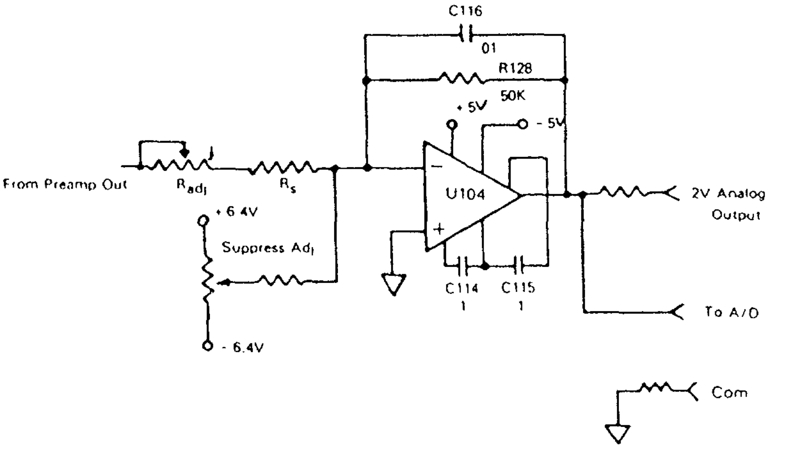


Figure 5-6. Model 614 Ranging Circuit

Table 5-3. Gain Selection

ꞦANGE VOLTS)	RESISTOR R_S	ADJUSTMENT	GAIN
.2	R125	R124	10
2	R129	R127	1
20	R130	R131	0.1

'e only exception to Table 5-3 is the 200kΩ range, which ects R129 and R127. This is required to scale the 2V full nge from the Resistance converter as described earlier.

04, C114, and C115 comprise a high-performance chop- r amplifier which eliminates the zero adjust for this stage. 16 and R128 are the feedback elements in this circuit ich set the gain (along with R_s described above) and the sponse time at the 2V analog output. Q105 and Q106 pro- de overload protection to this circuit. R205, R122 and 26 provide the suppression feature.

nce this is an inverting amplifier, the output at the 2V alog output is inverted in Volts and Resistance. It is not verted in Current and Charge, since it cancels the inver- on the preamplifier provides.

8 POWER SUPPLY

'e Power Supply can be broken down into several ctions:
Battery Charging Circuit
Battery Shutdown Circuit
DC - DC Converter

8.1 Battery Charging Circuit

e battery charging circuit is composed of U109, Q113, R104, R141, R144, and C120. Transformer T101 and its sociated components convert line voltage to 15VDC (pre- nt at TP3) which is filtered by C123. This voltage becomes e input to U109, which is an adjustable 3-terminal reg- ator. The output voltage from this regulator provides the at limit for the batteries of 9.5V. This voltage is set by 40.

ring charge the output voltage will be in the range of - 9.4V. The regulator will be saturated, which limits wer dissipation. Maximum current drawn through the gulator is 600mA. When the batteries become fully charg- (float charge), U109 trickle charges the batteries.

During float charge the battery voltage is maintained at 9.5V. As long as AC power is applied to the instrument, the batteries are maintained at this voltage. Current drawn from the regulator during float charge is essentially the current re- quired to power the circuitry, which is 200mA assuming the instrument is turned on.

When the AC line is disconnected, the voltage at the anode of CR104 decays (in about five seconds) to zero volts. This causes Q113 to turn off, disconnecting the regulator from the circuit. Thus, the batteries cannot discharge through U109 and associated components. When the line is recon- nected, Q113 turns back on, and causes U109 to regulate. Capacitor C120 stabilizes U109.

Battery fuse F101 will blow if the batteries are installed backwards or if a circuit fault develops which causes high battery currents to flow (> 2A).

5.8.2 Battery Shutdown Circuit

When the instrument is battery operated, it is necessary to limit the discharge level of the batteries to 7.4V. If this is not done, the ability of the batteries to hold a charge will be impaired.

To accomplish this, a low voltage detector consisting o. U107 and associated components is used. When the battery voltage is above 7.4V, the input to U107 (pin 2) is above the nominal threshold voltage of 1.15V. As soon as the battery voltage drops below 7.4V, U107 senses this and the output pin 3 (open collector) pulls low, turning on Q107 and shut- ting off Q109. This shuts off power to the instrument.

To prevent chatter, and to guarantee that the instrument does not turn on again until the batteries are charged above 8V, R133 provides hysteresis of 0.6V (referred to the battery terminals). Capacitor C119 prevents oscillations during the switching of U107.

5.8.3 DC to DC Converter

The battery voltage is used directly to supply the input to U108, which provides a regulated 5V to the A/D and display circuit. However, a DC to DC converter is required to con- vert the unipolar battery voltage into a regulated ±32V and -5V required by the preamplifier.

The heart of this converter is T102, Q110, and Q111. The clock circuit generates 100kHz which is divided down by

U105 to 25 kHz. Complementary drive is available directly from U105 and is used to drive Q110 and Q111. These transistors are power FETS - they turn on with 5V gate to source voltage and turn off with zero volt gate to source voltage. Together they drive T102 to create an AC output voltage at the secondary of T102. This AC voltage is rectified and filtered by CR105-107 and C117, C121, and C122.

A portion of the +32V output is fed back to Q112 which operates as an error amplifier whose output drives Q108. The reference for this amplifier is the 5V output from U108. Since Q108 drives the primary of T102, the composite circuit acts as a regulator which maintains ±32V and -5V in spite of battery voltage variations.

5.9 A/D CONVERTER

The Model 614 A/D Converter operates on the dual slope principle. The A/D circuitry consists of an integrated circuit U202 and its associated components. Internally the A/D converter operates as a 4½-digit converter with 20,000 counts full scale. The Volts and Charge functions are 4½-digit resolution, while the Current and Resistance function are 3½-digit resolution. The timing of the A/D converter is divided into three periods and is described in the following:

5.9.1 Auto Zero

The Auto Zero period is 100msec long which corresponds to 10,000 clock pulses. During this period, the reference voltage is stored on C-204. Also a feedback loop is closed around the integrator and comparator, charging the autozero capacitor C-203 (Pin 5, U202) to compensate for offsets within U202.

5.9.2 Signal Integrate

The Signal Integrate period is also 100msec long. Positive signals generate a negative going ramp at the integrator ou put. Negative signals generate a positive going ramp at th integrator output. The level of the integrated signal at th end of the signal integrate period is proportional to th average of the applied signal during this period. Since th signal integrate period lasts 100msec, the A/D converter ex hibits high normal mode rejection particularly 50 and 60H line frequencies. C202 is the integrator capacitor. R21(CR201 and R208 linearize the integrator.

5.9.3 Reference Integrate

The Reference Integrate period is 200msec long which co responds to 20,000 clock pulses. During this period th integrator is returned to baseline level by applying reference voltage of a polarity opposite to that of the signa The number of clock pulses required for the integrator t return to baseline level is proportional to the input signa These clock pulses are then counted and outputted to th display drivers U201 and U203 as multiplexed BCD data f DS201-DS206.

5.9.4 Zero Integrator

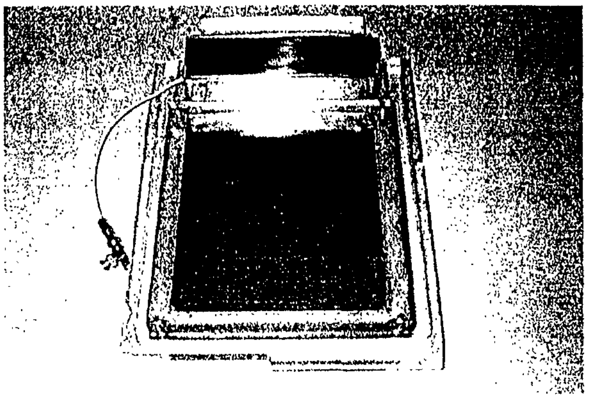
The final phase is zero integrator. During this phase th feedback loop is closed around input high, causing the i tegrator output (U202 Pin 4) to return to zero. Normally th phase will last from 1-2msec. During overrange this pha will last about 16msec.

5.9.5 Reference Circuit

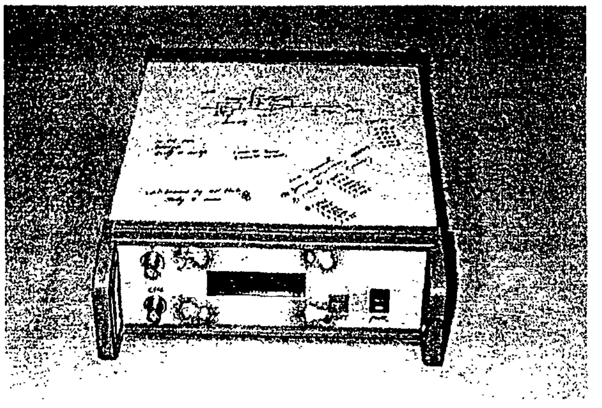
A precision 1.0000V reference is generated using U20 R211, R213 and R214 to provide constant current bias VR201. R203, R204 and R206 divide the 6.35V output VR201 to the necessary 1V level required by U202. R2 calibrates the reference.

Dosimetric System for Linacs QA Procedure

Air-Tight Ionization Chamber



Two-Channel Electrometer (Prototype)



Material and Methods:

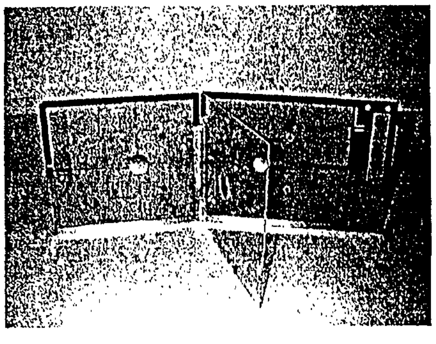
- 5cm backscattering acrylic plates
- 2/3/5cm buildup acrylic plates
- 1cc의 sensitive volume의 parallel plate chamber
- Rechargeable battery에 의한 high-voltage generator
- Cheap general coaxial cable이용
- 4.5Kg

Electrical Characteristics:

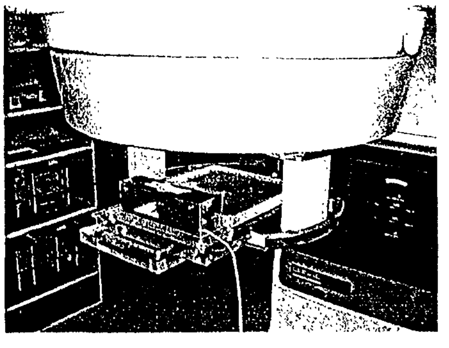
- Linearity: <0.5% (20MU to 320MU)
- Short/long-term stability: <0.5%
- Dose-rate effects: < 0.5% (80 - 400MU/min)
- Zero drift and leakage current: < 100fA

Features:

- Daily and weekly QA를 위한 ionization chamber
- TPC 보정이 필요 없는 air-tight type의 ionization chamber
- Can replace expensive foreign phantom materials
- Easy to carry and maintain
- Blocking tray-mounted settings (Easy to setup accurately)
- Possible to be used in SSD=100cm settings
- 350V for high-voltage generator (recombination factor: > 0.995)
- 한번 충전에 3개월 이상 사용가능
- > 20bit ADC 및 LCD Display
- RS232 interface (computer-controlled dosimetric system)



Schematic diagram of ionization chamber



Ionization chamber assembly inserted onto the blocking tray of linear accelerator

* Invented by SN Huh, Ph.D., CEO, and CTO of CodiSoft Co. ltd.
* 제작/판매원: (주) Codisoft, http://www.codi.net (TEL:02-3486-8050, FAX: 02-3486-6856)
* 국내특허 출원중 (2000년 11월 특허취득 예정)

(주) 본 제품의 연구/개발/상품화는 과학기술부 원자력 중장기계획의 연구의 결과이다.

```
/*===================================================*/
//      Title   : ADS1210
//      Author          : Lee,JongKuk
//      Date    : 2000/8/22
//
//      LCD             : Port D
//      ADC             : Port C
//      Mux             : Port B
//      Rs232c          : Port C
//      Relay   : Port A
//      ADC             : 17bit
//      function        : 2ch adc & display rs232 and lcd
/*===================================================*/
#include <pic.h>
#include "delay.c"          //delay functions
#include "sci.c"            //rs232 functions
#include "htlcd.c"          //lcd functions
#include "ads1210.c"        //ads1210 functions
#include "function.c"       //etc functions

unsigned char byte;
unsigned char flag;
unsigned char adflag = 0;

unsigned char interrupt isr(void){
        if(RCIF){
                byte = getch();
                flag = 1;
        }
        return byte;
}


void main(void){
        unsigned int ref1;
        unsigned int ref2;
        unsigned int value1;
        unsigned int value2;
        unsigned char temp;
        unsigned char i;

        di();           //disable interrupt

        DelayMs(200);
```

```
    TRISA = 0X00;
    TRISB = 0x80;       //portb.7 input other output
    TRISC = 0xa2;

    //portb change interrupt
    //RBIE = 1;
    //serial interrupt
    sci_Init();
    PIR1 = 0;
    PEIE = 1;
    GIE = 1;     //global interrupt enable
    RCIE = 1;    //rs232 receive interupt
    puts("ADS1210");
    adflag = 0;

    //lcd init.
    lcd_init();
    lcd_gotoxy(0,0);
    lcd_puts("ADS1210");
    PORTA = 0x00;
    PORTB = 0x10;     //calibration 1 0000

    /* calibration */
    relay(5);
    DelayMs(250);
    lcd_gotoxy(0,1);
    lcd_puts("Ads1210 Init");
    initadc();
    lcd_gotoxy(0,1);
    lcd_puts("            ");
    lcd_gotoxy(0,1);
    lcd_puts("Init END");
    DelayMs(200);
    readadc();
    relay(0);
    // wait
    DelayMs(250);

    /*read channel 0*/
    chchange(2);
    lcd_gotoxy(0,1);
    lcd_puts("CH0 : ");
 lcd_gotoxy(6,1);
    puts("CH0 : ");
    for(i=0;i<10;i++){
```

```
            ref1 = readadc();
        lcd_gotoxy(6,1);
            display(ref1);
            DelayMs(10);
    }

    /*read channel 1*/
    chchange(3);
    lcd_gotoxy(0,2);
    lcd_puts("CH1 : ");
lcd_gotoxy(6,2);
    puts("CH1 : ");

    for(i=0;i<10;i++){
            ref2 = readadc();
        lcd_gotoxy(6,2);
            display(ref2);
            DelayMs(10);
    }

    ei();

    relay(2);

    while(1){
            temp = PORTB&0x80;
            if((temp>>7) == 1){
                    lcd_gotoxy(0,3);
                    lcd_puts("adc start");
                    relay(2);
                    adflag = 1;
            }
            if((temp>>7) == 0){
                    lcd_gotoxy(0,3);
                    lcd_puts("adc stop ");
                    relay(0);
                    adflag = 0;
            }

            if(adflag)
            {
                    /*read channel 0*/
                    chchange(2);                    //ch2
                    lcd_gotoxy(0,1);
                    lcd_puts("CH0 : ");
```

```
	lcd_gotoxy(6,1);
		puts("CH0 : ");
		DelayMs(100);
		value1 = readadc();
		//display(value1);
		//calc

		if(value1 >= ref1){
			lcd_puts("+");
			puts("+");
			display((value1-ref1));
		}
		else{
			lcd_puts("-");
			puts("-");
			display((ref1-value1));
		}

		/*read channel 1*/
		chchange(3);					//ch3
		lcd_gotoxy(0,2);
		lcd_puts("CH1 : ");
	lcd_gotoxy(6,2);
		puts("CH1 : ");
		DelayMs(100);
		value2 = readadc();
		//display(value2);
		//calc

		if(value2 >= ref2){
			lcd_puts("+");
			puts("+");
			display((value2-ref2));
		}
		else{
			lcd_puts("-");
			puts("-");
			display((ref2-value2));
		}

}

if(flag)
{
		adflag = 0;
```

```
			switch(byte)
			{
				case 'H' :
				case 'h' :	help();
						break;
				/*
				case 't' :	adflag = 0;		//ad stop
						puts("ADC stop");
						lcd_gotoxy(0,3);
						lcd_puts("adc stop");
						putlf;
						break;
				case 's' :	adflag = 1;		//ad start
						puts("ADC start");
						lcd_gotoxy(0,3);
						lcd_puts("adc start");
						putlf;
						break;
				*/

				case 'a' :	relay(0);			//relay 1
						puts("Reset ON, Relay1 OFF,
Relay2 OFF");

						putlf;
						break;
				case 'b' :	relay(1);			//relay 2
						puts("Reset OFF,Relay1 OFF,
Relay2 OFF");

						putlf;
						break;
				case 'c' :	relay(2);			//relay 3
						puts("Reset OFF,Relay1 OFF,
Relay2 ON");

						putlf;
						break;
				case 'd' :	relay(3);			//relay 4
						puts("Reset OFF,Relay1 ON, Relay2
OFF");

						putlf;
						break;
				case 'e' :	relay(4);			//relay 5
						puts("Reset OFF,Relay1 ON, Relay2
ON");

						putlf;
						break;
```

```
                                        // RS232C data format change
                                        /*
                                        case 'f' :      dispFlag = 0;
                                                        puts("ADC value display Disable");
                                                        putlf;
                                                        break;
                                        case 'g' :      dispFlag = 1;
                                                        puts("ADC value display Enable");
                                                        putlf;
                                                        break;
                                        */
                                }
                                flag = 0;
                        }
                }
}
```

```
void toadc(unsigned char, unsigned char);
unsigned int readadc(void);
void initadc(void);

struct portd_pin_map{
        unsigned unused: 1;
        unsigned DRDY    : 1;
        unsigned DSYNC : 1;
        unsigned SCLK  : 1;
        unsigned SDIO     : 1;
        unsigned SDOUT : 1;
        unsigned          : 1;
        unsigned          : 1;
}ADC @0x07;

void toadc(unsigned char inst, unsigned char cmd){
    unsigned char i;
    if(ADC.DRDY==0)    while(!ADC.DRDY);
    while(ADC.DRDY);                              /* DRDY 핀이 0으로 떨어질때까지
기다림 */
    for(i=0;i<8;i++){               /* instruction 먼저 보내고 */
        ADC.SCLK = 1;
        ADC.SDIO = (inst&0x80)?1:0;
              ADC.SCLK = 0;
        inst<<=1;
    }
    for(i=0;i<8;i++){               /* command 보낸다 */
        ADC.SCLK = 1;
        ADC.SDIO = (cmd&0x80)?1:0;
        ADC.SCLK = 0;
        cmd<<=1;
    }
}


void initadc(void){
       while(ADC.DRDY);
       ADC.SCLK = 0;
       ADC.SDIO = 0;
       ADC.DSYNC = 1;

       while(ADC.DRDY);
       toadc(0x04, 0x12);
       while(ADC.DRDY);
       toadc(0x06, 0x07);
```

```
        while(ADC.DRDY);
        toadc(0x07, 0xa0);
        while(ADC.DRDY);
        toadc(0x05, 0x80);//calibration
}

unsigned int readadc(void){
    unsigned char d2,d1,d0;
    unsigned char buffer;
    unsigned char inst;
    unsigned char i;
    unsigned int value;
        d2 = 0;
        d1 = 0;
        d0 = 0;

    if(ADC.DRDY==0)    while(!ADC.DRDY);
    while(ADC.DRDY);

    inst = 0x80;
        for(i=0;i<8;i++){              /* instruction 먼저 보내고 */
         ADC.SCLK = 1;
         ADC.SDIO = (inst&0x80)?1:0;
         ADC.SCLK = 0;
         inst<<=1;
    }

    for(i=0;i<8;i++) {
        ADC.SCLK = 1;
        buffer = ADC.SDOUT;
        ADC.SCLK = 0;
        d2 |= (buffer<<(7-i));
    }

    inst = 0x81;
    for(i=0;i<8;i++){              /* instruction 먼저 보내고 */
        ADC.SCLK = 1;
        ADC.SDIO = (inst&0x80)?1:0;
        ADC.SCLK = 0;
        inst<<=1;
    }

    for(i=0;i<8;i++) {
        ADC.SCLK = 1;
        buffer = ADC.SDOUT;
```

```
        ADC.SCLK = 0;
        d1 |= (buffer<<(7-i));
    }

      inst = 0x82;
    for(i=0;i<8;i++){              /* instruction 먼저 보내고 */
        ADC.SCLK = 1;
        ADC.SDIO = (inst&0x80)?1:0;
        ADC.SCLK = 0;
        inst<<=1;
    }

    for(i=0;i<8;i++) {
        ADC.SCLK = 1;
        buffer = ADC.SDOUT;
        ADC.SCLK = 0;
        d0 |= (buffer<<(7-i));
    }

    value = ((d2 << 1) << 8) | (d1<<1) | (d0>>7);
      return(value);
    /*display(value);

      if(dispFlag == 0){
              putch(d2);
              putch(d1);
              putch(d0);
              puts("V");
              putlf;
      }
      */
}
```

```
/*
 *      Delay functions
 *      See delay.h for details
 *
 *      Make sure this code is compiled with full optimization!!!
 */

#include    "delay.h"

void
DelayMs(unsigned char cnt)
{
#if     XTAL_FREQ <= 2MHZ
        do {
                DelayUs(996);
        } while(--cnt);
#endif

#if    XTAL_FREQ > 2MHZ
        unsigned char       i;
        do {
                i = 4;
                do {
                        DelayUs(250);
                } while(--i);
        } while(--cnt);
#endif
}
```

```
unsigned char chdata;
unsigned char multi;
void chchange(unsigned char ch){
	switch(ch){
		case 1 :	chdata = 0x11;
				PORTB = chdata;
				break;
		case 2 :	chdata = 0x12;
				PORTB = chdata;
				break;
		case 3 :	chdata = 0x13;
				PORTB = chdata;
				break;
		case 4 :	chdata = 0x14;
				PORTB = chdata;
				break;
		case 5 :	chdata = 0x15;
				PORTB = chdata;
				break;
		case 6 :	chdata = 0x16;
				PORTB = chdata;
				break;
		case 7 :	chdata = 0x17;
				PORTB = chdata;
				break;
		case 8 :	chdata = 0x18;
				PORTB = chdata;
				break;
		case 9 :	chdata = 0x19;
				PORTB = chdata;
				break;
		case 10 :	chdata = 0x1a;
				PORTB = chdata;
				break;
		case 11 :	chdata = 0x1b;
				PORTB = chdata;
				break;
		case 12 :	chdata = 0x1c;
				PORTB = chdata;
				break;
		case 13 :	chdata = 0x1d;
				PORTB = chdata;
				break;
		case 14 :	chdata = 0x1e;
				PORTB = chdata;
```

```
                    break;
          case 15 : chdata = 0x1f;
                    PORTB = chdata;
                    break;
     }
}

void relay(unsigned char onoff){
     switch(onoff){
          case 0:   PORTA = 0x00;
                    lcd_gotoxy(9,3);
                    lcd_puts("RST- - ");
                    break;

          case 1:   PORTA = 0x01;
                    lcd_gotoxy(9,3);
                    lcd_puts(" - - R2");
                    multi = 6;
                    break;

          case 2:   PORTA = 0x03;
                    lcd_gotoxy(9,3);
                    lcd_puts(" - R1R2");
                    multi = 60;
                    break;

          case 3:   PORTA = 0x05;
                    lcd_gotoxy(9,3);
                    lcd_puts(" - - - ");
                    multi = 1;
                    break;

          case 4:   PORTA = 0x07;
                    lcd_gotoxy(9,3);
                    lcd_puts(" - R1- ");
                    multi = 10;
                    break;

          case 5:   PORTA = 0x08;
                    break;

          default : break;
     }
}
```

```
void help(void){
	//relay on = acf2101 reset = logic0
	//relay1 off = *10
	//relay2 off = *6

	puts("a : Reset ON, Relay1 OFF, Relay2 OFF");	putlf; //always 0	1
	puts("b : Reset OFF,Relay1 OFF, Relay2 OFF");	putlf; //*60		1
	puts("c : Reset OFF,Relay1 OFF, Relay2 ON");		putlf; //*10
	puts("d : Reset OFF,Relay1 ON, Relay2 OFF");		putlf; //*6
	puts("e : Reset OFF,Relay1 ON, Relay2 ON");		putlf; //*1

	puts("f : ADC Value Display Disable");putlf;
	puts("g : ADC Value Display Enable");putlf;
}
```

```
//      LCD functions
//
//      PIN Definition
//      LCD         PIC

//      Enable      RD0
//      RS          RD1
//      RW          RD2
//      data        RD4~RD7   4bit
/*==========================================================*/
/*                  LCD Functions                          */
/*==========================================================*/

void nop(void);
unsigned char lcd_read_byte(void);
void lcd_send_nibble( unsigned char );
void lcd_send_byte( unsigned char, unsigned char );
void lcd_init(void);
void lcd_gotoxy( unsigned char, unsigned char );
void lcd_putc( unsigned char );
void lcd_puts(const char * s);
void display( unsigned int );

#define lcd_type        2
#define lcd_line_two    0x40

unsigned char dispFlag = 1;

struct lcd_pin_map{
        unsigned rs : 1;
        unsigned rw         : 1;
        unsigned enable: 1;
        unsigned unused: 1;
        unsigned data       : 4;
}lcd @0x08;

unsigned char const LCD_INIT_STRING[4]={0x20|(lcd_type<<2), 0xc, 1,6};

void nop(void){
        asm("nop");
}

unsigned char lcd_read_byte(void){
        unsigned char high, low;
```

```
        TRISD = 0xf0;
        lcd.rw = 1;
        nop();
        lcd.enable = 1;
        nop();
        high = lcd.data;
        lcd.enable = 0;
        nop();
        lcd.enable = 1;
        DelayUs(1);
        low = lcd.data;
        lcd.enable = 0;
        TRISD = 0x00;
        return((high << 4)|low);
}

void lcd_send_nibble( unsigned char n ) {
    lcd.data = n;
    nop();
    lcd.enable = 1;
    DelayUs(2);
    lcd.enable = 0;
}

void lcd_send_byte(unsigned char address, unsigned char n){
    lcd.rs = 0;
    while((lcd_read_byte()&0x80)!=0);                //busy
    lcd.rs = address;                                //0:input instuction 1:input
data
    nop();
    lcd.rw = 0;                                      //0:write 1: read
    nop();
    lcd.enable = 0;
    lcd_send_nibble(n >> 4);                         //send high value
    lcd_send_nibble(n & 0xf);                //send low value

}

void lcd_init(void) {
        unsigned char i;
        TRISD = 0x00;
    lcd.rs = 0;
    lcd.rw = 0;
    lcd.enable = 0;
    DelayMs(15);
```

```
    for(i=1;i<=3;++i) {
        lcd_send_nibble(3);
        DelayMs(5);
    }
        lcd_send_nibble(2);

        for(i=0;i<=3;++i)
        lcd_send_byte(0, LCD_INIT_STRING[i]);
}

void lcd_gotoxy( unsigned char x, unsigned char y) {
        unsigned char address;
    switch(y){
         case 0  :   address = 0x80 + x;
                    break;
         case 1  :   address = 0xC0 + x;
                    break;
         case 2  :   address = 0x90 + x;
                    break;
         case 3  :   address = 0xD0 + x;
                    break;
        }
        lcd_send_byte(0, address);              //function
}

void lcd_putc( char c) {
        lcd_send_byte(1,c);
}


void lcd_puts(const char * s){
        //LCD_RS = 1;      // write characters
        while(*s) lcd_putc(*s++);
}

char lcd_getc( unsigned char x, unsigned char y) {
        unsigned char value;
        lcd_gotoxy(x,y);
        lcd.rs=1;
        value = lcd_read_byte();
        lcd.rs=0;
        return(value);
}

void display(unsigned int value1){
```

```
    unsigned char Fportion,Sportion,Tportion,F4portion,F4balance;
    long Value;
    long Fbalance;
    long Sbalance;
    long Tbalance;

    Value = (10.000 * value1)/13.107;
    Fportion = Value / 10000;
    Fbalance = Value % 10000;
    Sportion = Fbalance / 1000;
    Sbalance = Fbalance % 1000;
    Tportion = Sbalance / 100;
    Tbalance = Sbalance % 100;
    F4portion = Tbalance / 10;
    F4balance = Tbalance % 10;

    lcd_putc(0x30+Fportion);
    lcd_putc(0x2e);
    lcd_putc(0x30+Sportion);
    lcd_putc(0x30+Tportion);
    lcd_putc(0x30+F4portion);
    lcd_putc(0x30+F4balance);
    lcd_putc(0x56);

        if(dispFlag){

                putch(0x30|Fportion);
                putch(0x2e);        //. = 0x2E
            putch(0x30|Sportion);
        putch(0x30|Tportion);
            putch(0x30|F4portion);
        putch(0x30|F4balance);
            putch(0x56);    //V = 0x56
                putlf;
        }
}
```

```
//#include <pic.h>
//#include "sci.h"

#define FOSC      (4000000L)
#define SCI_EIGHT       (0)
#define SCI_NINE (1)

//unsigned char    sci_Init(unsigned long int, unsigned char);
unsigned char      sci_Init(void);
void          putch(unsigned char);
unsigned char      getch(void);
void          PutNinth(unsigned char);
unsigned char      GetNinth(void);
unsigned char      GetFERR(void);
unsigned char      CheckOERR(void);
void puts(register const char *);

#define putlf putch(13);putch(10)

/* Routines for initialisation and use of the SCI
 * for the PIC processor.
 */

/* other options:
 * frame errors
 */

//unsigned char sci_Init(unsigned long int baud, unsigned char ninebits){
unsigned char sci_Init(void){
	//int X;
	//unsigned long tmp;

	/* calculate and set baud rate register */
	/* for asynchronous mode */
	/*
	tmp = 16UL * baud;
	X = (int)(FOSC/tmp) - 1;

	if((X>255) || (X<0))
	{
		tmp = 64UL * baud;
		X = (int)(FOSC/tmp) - 1;
		if((X>255) || (X<0))
		{
			return 1;
```

```
            }
            else
                BRGH = 0;
        }
        else
            BRGH = 1;
        SPBRG = X;
        */
        SPBRG = 25;
        BRGH = 1;
        SYNC = 0;   /* asynchronous */
        SPEN = 1;   /* enable serial port pins */
        CREN = 1;   /* enable reception */
        SREN = 0;   /* no effect */
        TXIE = 0;   /* disable tx interrupts */
        RCIE = 0;   /* disable rx interrupts */
        //TX9  = ninebits?1:0;    /* 8- or 9-bit transmission */
        //RX9  = ninebits?1:0;    /* 8- or 9-bit reception */
        TX9  = SCI_EIGHT?1:0;   /* 8- or 9-bit transmission */
        RX9  = SCI_EIGHT?1:0;   /* 8- or 9-bit reception */
        TXEN = 1;   /* enable the transmitter */

        return 0;
}

void putch(unsigned char byte){
        while(!TXIF) /* set when register is empty */
            continue;
        TXREG = byte;

        return;
}

unsigned char getch(void){
        while(!RCIF) /* set when register is not empty */
            continue;

        return RCREG;       /* RXD9 and FERR are gone now */
}

unsigned char CheckOERR(void){
        if(OERR)      /* re-enable after overrun error */
        {
            CREN = 0;
            CREN = 1;
```

```
		return 1;
	}

	return 0;
}

#define PutNinth(bitnine)	(TX9D = bitnine?1:0;)

unsigned char GetNinth(void){
	while(!RCIF)
		continue;

	return RX9D;	/* RCIF is not cleared until RCREG is read */
}

unsigned char GetFERR(void){
	while(!RCIF)
		continue;

	return FERR;	/* RCIF is not cleared until RCREG is read */
}

void puts(register const char *str)
{
	while((*str)!=0)
	{
		putch(*str);
		str++;
	}
}
```