

**한 · 우크라이나 간 섬광형 방사선
계측기술 기반연구를 위한
국제협력연구**

**An International Cooperation Research for
Construction of Scintillation Detector
Technology between Korea and Ukraine**

연구기관
한양대학교

과 학 기 술 부

제 출 문

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본 보고서를 "한·우크라이나 간 섬광형 방사선 계측기술 기반연구를 위한 국제협력연구" 과제의 최종보고서로 제출합니다.

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요약(연구결과를 중심으로 개조식 500자 이내)					면수
<p>1. 연구개발목표 및 내용</p> <ul style="list-style-type: none"> ○ 섬광형 방사선 계측기 관련 선진 기술 동향 및 선진 기술 개발 사례를 파악 ○ 한·우크라이나간 국제협력기반 조성 및 타 협력사업을 위한 연구 네트워크 구축 ○ 섬광형 방사선 계측기 관련 핵심기술 확보를 위한 국제협력방안 마련 <p>2. 연구결과</p> <ul style="list-style-type: none"> ○ 섬광형 방사선 계측기 관련 선진 기술 사례 및 동향 분석 <ul style="list-style-type: none"> - Joint 세미나 및 ISC 전문가 초청 등을 통한 기술동향 분석 - 우크라이나 주요 연구소 현장방문 등을 통한 선진 기술 사례 파악 ○ 우크라이나 ISC 연구소 연구원 및 국내 전문가가 참여하는 학술 세미나 2회 개최 ○ ISC 전문가 초청 세미나 개최 ○ 국내 섬광형 방사선 계측기 관련 핵심 기술 개발 현황 조사 ○ 섬광형 방사선 계측기 핵심 기술 확보를 위한 국제협력 방안 마련 <p>3. 기대효과 및 활용방안</p> <ul style="list-style-type: none"> ○ 우크라이나의 섬광형 방사선 계측기 기술 관련 선진기술 및 핵심기술 등을 습득하기 위한 국제협력방안 모색에 활용될 수 있음. ○ 기 구축된 섬광형 방사선 계측기술 관련 국제협력기반 및 기술인력 간 연구 네트워크를 이용 향후 전개될 타 연구 사업이 효과적으로 공동연구를 수행할 수 있도록 하는데 활용될 수 있음. 					

요 약 문

I. 제 목

한 · 우크라이나 간 섬광형 방사선 계측기술 기반연구를 위한 국제협력 연구

II. 연구개발의 목적 및 필요성

방사선 계측기 및 이용 장비 분야 기술은 원자력 발전 분야 뿐 만 아니라 비파괴 산업, 의료용 방사선 진단 및 치료 장비, 기초연구 등에 핵심 요소 기술로 활용되고 있으며 일반산업분야까지 폭넓게 활용되는 기술로서 관련 산업과 경제에 미치는 파급효과가 매우 큰 기술이다. 그럼에도 불구하고, 국내 산업은 방사선 계측기 센서에서 시스템까지 전량 수입에 의존하고 있는 실정이다. 현재, 방사선 계측기 기술 개발을 위한 산 · 학 · 연 협동 연구가 수행 중에 있고 해외 현지연구실 설치와 같은 국제공동연구가 시도되고 있으나 전체 방사선 계측 기술 연구 범위에 비하면 극히 제한적으로 진행되고 있다.

한국과 우크라이나는 2001년 7월 23일 국가 간 원자력협력 협정을 통해 원자력 분야에서 적극적인 협력을 추진키로 합의한 바 있어 국가차원의 지원을 얻기가 용이한 상태이다. 한편, 우크라이나의 ISC(Institute for Single Crystals) 연구소는 구 공산치하에서 축적된 기초기술의 경제적 활용(상용화, 해외이전 등)을 강력히 추진하고 있기 때문에 고급 기초 기술의 이전이 용이하며 우크라이나 자체의 경제적 어려움으로 인해 서방에 비해 활용성이 높은 구소련의 축적된 높은 기초기술을 비교적 낮은 비용으로 획득할 수 있다는 장점이 있다.

III. 연구개발의 내용 및 범위

본 과제의 목표는 첫째로 한 · 우크라이나 양국의 전문가들을 초청한 Joint 국제 세미나 및 ISC 전문가를 초청한 국내 세미나를 개최하고, 산 · 학 · 연 전문가들로 팀을 구성 우크라이나 현지연구소를 방문함으로써 섬광형 방사선 계측기 관련 선진 기술 동향 및 선진기술 개발사례를 확인하

고 파악하는데 있다. 둘째는 인력교류(국제 세미나 및 전문가초청 세미나 개최)를 통한 한·우크라이나 간 국제협력기반 조성 및 이를 바탕으로 타 연구사업의 지속적인 협력 사업을 전개시키기 위한 연구 네트워크를 구축하는데 있다. 셋째로, 섬광형 방사선 계측기 관련 국내 핵심기술 개발현황을 조사하고 핵심기술 확보를 위한 국제협력방안을 마련하는데 있다.

IV. 연구개발결과

섬광형 방사선 계측기 관련 선진 기술 사례 및 동향 분석을 위해 Joint 세미나 및 ISC 전문가들을 초청하여 국내 세미나를 개최하였다. 또한, 산·학·연 전문가 팀을 구성하여 우크라이나 주요 연구소들을 방문하여 선진 기술 사례들을 파악하였다.

국제협력지지 기반 및 기술인력 간 연구 네트워크를 구축하기 위하여 ISC 연구소의 연구원 및 국내 전문가가 참여하는 학술 세미나를 한국과 우크라이나에서 각 1회씩 2회 개최하였다. 또한, ISC 연구소의 계측기 관련 전문가인 Dr. Ryzhykov 및 Dr. Gektin을 초청 국내 세미나를 개최하였다.

핵심 기술 확보를 위하여 국내의 섬광형 방사선 계측기 관련 핵심 기술 개발 현황 조사 및 이를 위한 국제협력 방안을 모색하였다. 국제협력지지 기반 및 기술인력 간 연구 네트워크 강화를 위하여 양국 간 Joint 국제 세미나의 정례화 및 기술인력 교류의 확대를 위한 방안을 제시하였으며 국제공동연구를 위한 정부차원의 계획수립 지원을 위한 기초 자료를 제공하였다.

V. 연구개발결과의 활용계획

Joint 국제 세미나, ISC 전문가 초청 국내 세미나 및 ISC 현지연구실 기술인력 교류 등으로 국제협력기반 조성 및 기술인력 간 연구 네트워크가 구축되었다. 이 구축된 국제협력기반을 통해 향후 전개될 타 연구사업의 국제협력연구를 효율적으로 수행할 수 있는 환경이 구축되었다.

세미나 개최, 인력교류, ISC 및 PMP(Pure Metals Plant) 등의 연구소 현장방문 등을 통해 우크라이나의 섬광형 방사선 계측기 기술 관련 선진 기술들을 파악하였다. 본 연구는 향후 국제협력이 요구되는 타 연구사업의 주요 핵심기술들에 대한 국제협력방안을 모색하는데 활용될 수 있다.

SUMMARY

I. Project Title

An International Cooperation Research for Construction of Scintillation Detector Technology between Korea and Ukraine

II. Objectives and Necessities of the Project

The radiation detector and its application play an important role in the field of radiation technology (RT) such as the non-destructive industry and medical radiation diagnosis treatment as well as in the field of power plant. Furthermore, it is expected to contribute in promoting the welfare of the people and the related industry and economy.

Although the radiation technology is widely used in a lot of fields, most of radiation detector sensor and its related systems have been imported.

In Korea, some cooperation research is being carried out for development of radiation detector technology participating industry, university, and research institute. Meanwhile, international cooperation research is being attempted to establish the oversea local laboratory, but there are many difficulties to keep the cooperation research in these days.

Korea and Ukraine have agreed to work together positively in nuclear energy field from arranging the nuclear energy cooperation agreement between the two nations in July 3, 2001. Therefore, our country had a more opportunity to get the high technology of Ukraine through cooperation with many research institutes in Ukraine since agreement. Meanwhile, Ukrainian research institutes such as ISC (Institute for Single Crystals) also hope to cooperate with foreign countries to utilize the fundamental technology

cumulated under the rule of communism. It will be possible to cut down the cost to transfer the high technology of Ukraine by this situation.

III. Scope and Contents of the Project

This project has three final goals. The first is to investigate the state-of-the-art and the tendency of the scintillation detector technology and tendency through inviting the ISC experts developing the scintillation detector and visiting the important research institutes in Ukraine

The second is to build the research network to continue to keep the cooperation foundation between Korea and Ukraine from exchanging manpower.

The third is to investigate the present development condition concerned with scintillation detector and the international cooperation plan between Korea and Ukraine to obtain the key technology.

IV. Accomplishments and Impact of the Research

To investigate the advanced technology of Ukraine and state-of-the-art of scintillation detector technology, two international joint seminars were held and ISC experts were invited to present the situation of detector development in Ukraine. A domestic detector expert team participating industry, university, and research institute had been organized and visited several primary research institutes (ISC, PMP, KIPT, etc.) in Ukraine to investigate the high and new technologies.

The two international joint seminars between Korea and Ukraine were held to build the research network for supporting international cooperation. Two seminars for introducing the high

and new technologies in relating to the scintillation detector were held in our countries. Dr. Ryzhykov and Dr. Gektin who has been the expert of scintillation detector of ISC were invited to the seminars, individually.

The present status of our development and the international cooperation plan for obtaining the key technology of the scintillation detector were examined and considered. To inspire the relationship between two countries and increase the exchange of researcher and information, the current international joint seminar should be regularly held.

Meanwhile, some fundamental information needed for promoting the international cooperation of the government was provided through this study.

V. Application Plan of the Research Results

Human network for research between Korea and Ukraine were established and the investigation into the high and new technology about the scintillation detector was carried out through holding the international joint seminar and inviting the ISC experts, and visiting the Ukraine research group.

Using previously constructed research network, the international cooperation will be effectively carried out on the other field in the future.

The high and new technology about the scintillation detector was investigated through holding international joint seminar, inviting the ISC experts, and visiting the Ukraine research institutes. Through this study, some proposal for obtaining its primary technology and keeping the concrete relationship between the two countries were investigated.

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제 1 장 서 론

제 1 절 연구개발의 필요성

방사선 계측기 및 이용 장비 분야 기술은 원자력 발전 분야 뿐 만 아니라 일반산업분야까지 폭넓게 활용되는 기술이다. 따라서 방사선 계측기 설계 및 제작 기반 기술의 국내 확보가 가능해지면 관련 산업과 경제에 미치는 파급효과가 매우 크리라고 예상된다. 또한, 방사선 계측기 기술 분야는 비파괴 산업, 의료용 방사선 진단 및 치료 장비, 기초연구 등에 핵심 요소 기술로 활용되고 있으며 방사성동위원소와 방사선 계측기를 이용한 의료용 진단 및 치료 분야에서 선진의료 혜택을 제공함으로써 국민 복지 향상에 크게 기여할 수 있는 기술이다.

그러나 방사선 계측 기술은 기초과학에서부터 방사선 방호, 핵물질 통제, 의학적 이용에 이르기까지 폭 넓게 활용되는 기술이다. 그러나 국내 산업은 방사선 계측기 센서에서 시스템까지 전량 수입에 의존하고 있는 실정이다. 한편, 방사선 계측기 기술 개발을 위한 산·학·연 협동 연구가 우리나라에서 현재 수행 중에 있고 해외 현지연구실 설치와 같은 국제공동연구가 시도되고 있으나 단발적이며 전체 방사선 계측 기술 연구 범위에 비하면 극히 부분적인 실정이다. 한편, 방사선 계측기 관련 세계 선도기술 보유 기관들은 체르노빌 원전사고 이후 방사선 안전 및 계측 관련 연구에 더욱 주력하여 CZT(CdZnTe)나 BGO(Bi₄Ge₃O₁₂) 상온 반도체 센서 개발, 대형 NaI 센서를 이용한 산업/의료용 영상기기 개발 등 괄목할 만한 진척을 보이고 있어 국내와의 기술 격차가 날로 커지고 있는 실정이다.

한국과 우크라이나는 2001년 7월 23일 국가간 원자력협력 협정을 맺고, 『한·우크라이나 과학기술협력센터 설치, 운영』, 『과학기술 공동 세미나/심포지움 개최 정례화』, 『공동연구과제 추진』 등을 통해 원자력 분야에서 적극적인 협력을 추진키로 합의한 바 있어 국가차원의 지원을 얻기가 용이한 장점을 가지고 있다. 또한, 우크라이나의 일부 연구소는 구 공산치하에서 축적된 기초기술의 경제적 활용(상용화, 해외이전 등)을 강력히 추진하고 있기 때문에 고급 기초기술의 이전이 용이하고 한편, 우크라이나 자체의 경제적 어려움으로 인해 우리나라 입장에서 보면 서방에 비해 활용

성이 높은 첨단 기술들을 비교적 낮은 비용으로 습득할 수 있는 장점을 가지고 있다.

현재, 방사선안전신기술연구센터(이하 iTRS)는 기술이전에 협조적이며 첨단 계측기 및 계측기 센서 개발 능력이 있는 우크라이나의 ISC 연구소와 협약을 맺고 현지연구실을 설치 및 연구원 파견 등을 통해 공동연구를 수행하고 있다. 우크라이나 카르코프 소재 ISC(Institute for Single Crystals, Kharkov, Ukraine) 연구소는 1961년 설립되어 현재 1,100여 명의 연구진을 갖고 있는 세계 최대 단결정 전문연구소로 특히 BGO, CZT 등 방사선 계측기용 결정(Crystal) 분야에서 세계 최고의 기술력을 보유하고 있다. 또한, 방사선 계측기 센서용 고 순도의 대형 단결정을 PMP(Pure Metals Plant)와의 협력으로 생산하여 Siemens, EG&G사 등 세계적인 첨단 계측장비 제조사에 공급하고 있다. 한편, ISC는 자신들이 생산한 센서를 이용 산업/의료용 계측기도 생산하는 등 기술의 상업적 활용에도 주력하고 있어 국내의 방사선 계측기 연구기술을 향상시키기 위한 국제협력 및 국제공동연구를 이끌어내는데 용이한 장점을 가지고 있다.

제 2 절 연구개발 목적

- 한·우크라이나 간 전문가 초청 국제 세미나, 산·학·연 전문가들로 팀을 구성하여 우크라이나 현지연구소들을 방문하여 섬광형 방사선 계측기 관련 선진 기술 동향 및 선진 기술 개발 사례를 파악.
- 인력교류(국제 세미나 및 전문가초청 세미나 개최)를 통한 한·우크라이나 간 국제협력기반을 조성하고 및 이를 바탕으로 국제협력연구 사업을 전개시키기 위한 연구 네트워크를 구축.
- 섬광형 방사선 계측기 관련 국내 핵심기술 개발현황 조사 및 핵심기술 확보를 위한 한/우크라이나 간 국제협력방안을 마련.

제 3 절 추진전략

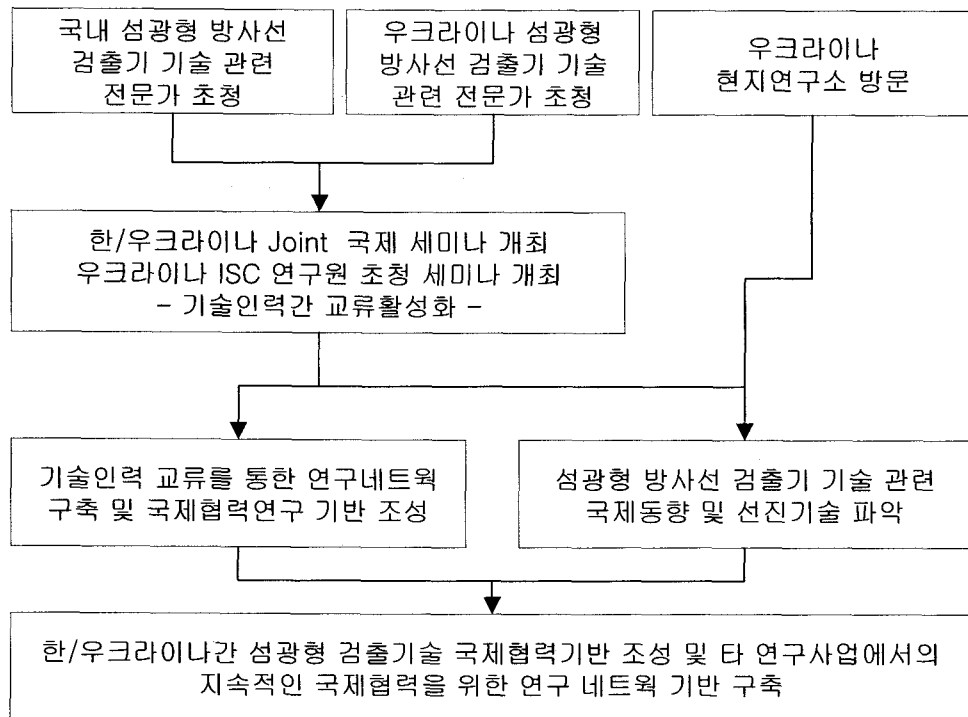


그림 1. 한 · 우크라이나 간 국제협력을 위한 추진전략 개념도

제 2 장 연구개발 수행내용 및 결과

제 1 절 국내·외 기술개발 현황

1. 섬광형 방사선 계측기 국내 기술개발 현황

방사선 계측기 기술은 Radiation Technology(RT)의 핵심 요소기술이지만 우리나라는 방사선 계측기 소재 및 센서 분야 기술이 매우 취약하여 대부분을 수입에 의존하고 있다.

국내에서는 iTRS, KAERI, 한양대학교, KAIST, 일부 벤처기업 등을 중심으로 방사선 계측기 기술개발 연구가 진행 중에 있다. 현재 진행되고 있는 기술개발 현황을 간단히 살펴보면 KAERI에서는 2002년에 원자력 중장기 과제로 5년간 수행될 '계측기 설계 및 제작 기술 개발' 과제를 통하여 방사선 계측기 설계/제작 기반시설 및 기술 확보와 계측기 기술의 산·학·연 이용자 지원체계를 확립하고자 추진 중에 있다.

KAERI에서 개발 중인 방사선 계측기로는 그림 2와 그림 3에서 보는바와 같이 Gas Detector로서 RMS(Radiation Monitoring System)와 BMS(Beam Loss Monitoring System)를 위한 Ion Chamber와 GEM(Gas Electron Multiplier) Detector 등이 있다. 섬광형 계측기로는 두께 측정을 위한 CsI(Tl)와 β -Ray RMS용 Plastic Scintillator 등이 있으며 Silicon Detector의 경우에는 기초연구가 진행 중에 있다.

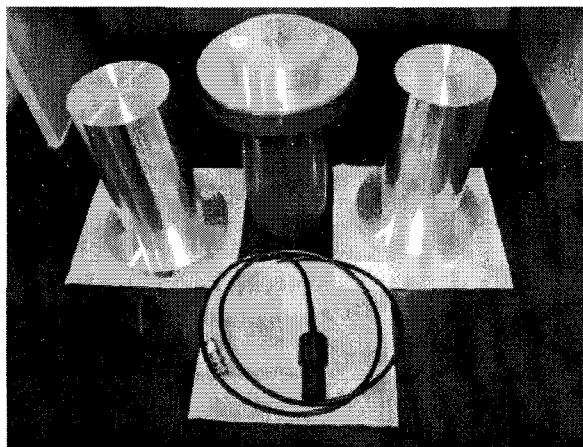


그림 2. Ion Chamber (KAERI)

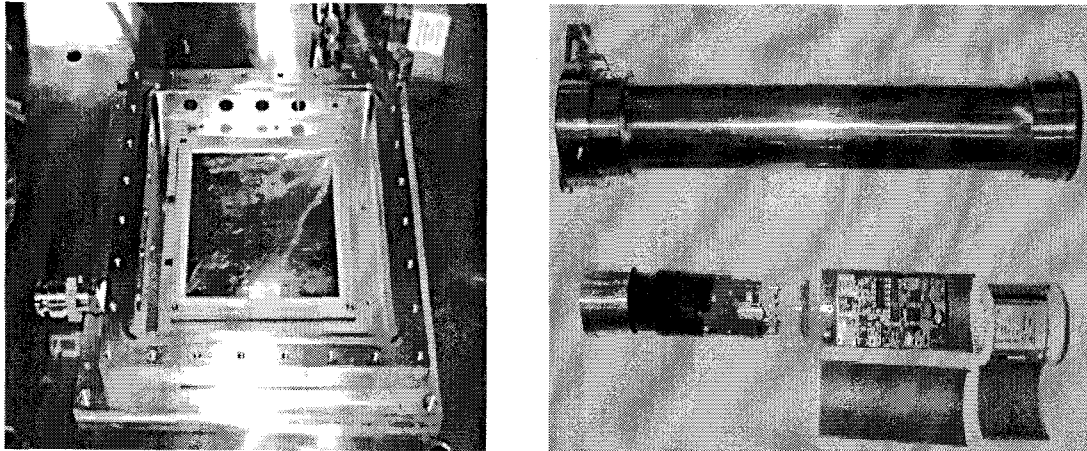


그림 3. KAERI에서 제작중인 GEM Detector와 CsI(Tl) 섬광형 계측기

한양대학교와 KAIST에서는 X-ray 및 중성자를 이용한 공항 검색시스템에 대한 연구가 활발히 진행 중이며, KAERI에서는 향후 CZT나 CdTe 계측기 및 상온 반도체 센서를 이용한 새로운 RMS 시스템 개발과 관련된 연구를 추진하고자 계획하고 있다.

한편, iTRS는 우크라이나의 ISC 연구소와 현지연구실 협약을 2002년 3월부터 체결하고 섬광형 방사선 계측기 관련 기술을 습득하기 위하여 지속적으로 석사 및 박사급 인력을 파견하고 있다. 연구 인력 파견을 통하여 생체조직등가 방사선 계측기 개발을 위한 액정 물질 특성 분석, 중성자 계측용 LiPO_3 유리 섬광체 기술개발 및 감마 모니터링 시스템용 CZT 센서 특성 연구 등과 관련된 연구를 수행하고 있다.

2. 섬광형 방사선 계측기 선진 기술 사례 및 동향 연구

협력연구의 일환으로 이미 기존의 국제협력기반을 갖고 있는 iTRS를 중심으로 산(국내의 모 기업체) · 학(KAIST) · 연(KAERI) 방사선 계측기 관련 전문가 팀을 구성하여 우크라이나 현지의 주요연구소(ISC, PMP, KIPT 등)들의 현장시설을 직접 방문하였으며 이를 통해 현지의 방사선 계측기 관련 핵심 요소기술 및 기술동향들을 파악하였다.

표 1. 산·학·연 방사선 계측기 관련 전문가 팀이 방문한 우크라이나의 주요 연구소 및 주요 접촉 인사들의 인적사항

기관	성명	소속 및 직책	비고
ISC	Prof. Boris Grinyov	Director, Institute for Scintillation Materials, National Academy of Science of Ukraine	
	Prof. Vladimir Ryzhikov	Director, Scientific-Technological Center of Radiation Instruments, Institute for Single Crystals, National Academy of Science of Ukraine	
	Dr. Valentin Chebanov	Academic Secretary, Institute for Single Crystals, National Academy of Science of Ukraine	
	Prof. Longin Lysetskiy		⁶ Li(Eu), Stilbene, Anthracene, p-terphenyl for neutron detector
	Dr. Vyacheslav Puzikov		CZT detector
KIPT	Prof. Ivan Karnaukhov	Vice-Director, Kharkov Institute of Physics and Technology, National Science Center	
	Prof. Mykola Ayzatskiy	Deputy Director of Accelerator for Scientific Work, National Science Center, Kharkov Institute of Physics and Technology	
PMP	Vladimir I. Komlach	Director of PMP	
	Volodymyr M. Volkov	Mayor of Sritlovodsk City	
	Hrigoriy Petrov	The First Deputy Mayor of Sritlovodsk City	
	Prof. Yuriy M. Gavrylyuk		
	Prof. Anatoly P. Oksanich		
IHEPNP	Prof. Dovbnaya	Director of IHEPNP, Director of Accelerator	

현재 우크라이나의 ISC 연구소는 방사선 계측 센서의 소재분야에 있어 세계 최고 수준의 원천기술을 확보하고 있다. 특히 Alkali Halide 섬광체 (NaI, CsI 등), 복합 산화물 섬광체(CdWO₄, GSO, PWO, BGO) 단결정 제조 및 가공 기술이 우수하다. ISC 연구소는 방사선 계측의 최신예 차세대 기술인 CZT 상온 반도체를 이용한 방사선 계측기 개발 분야에서 미국의 미시간 대학(Prototype 수준)과 더불어 세계 최고의 수준을 보유하고 있으며 이와 관련하여 방사선 영상화 기술 등의 첨단기술들을 이미 개발하였으며 기술축적 면에서 세계적인 우위를 보이고 있다.

현재 3가지 형태, 11가지 종류의 CZT 방사선 계측기를 제작, 판매하고 있으며 성능(에너지 분해능 2% 이하) 또한 세계적 수준이다. 특히, CZT 방사선 계측기는 휴대가 간편하여 원전 등에서 방사선작업자들의 방사선 피폭 감시를 위한 계측장비로서 그 활용도가 높아 연구개발이 더욱더 활발히 진행되고 있다.

ISC 연구소는 생산될 섬광체의 특성분석 및 테스트를 미리 수행할 수 있는 설계 및 시뮬레이션 기술을 보유하고 있으며 대규모 결정성장(Single Crystal Growing) 자동화 시스템을 개발하여 원료물질부터 결정성장 및 중간처리 단계를 거쳐 생산되는 섬광체 생산 공정을 자동화 하고 있다. 이러한 시스템을 이용하여 여러 종류 및 크기의 섬광체를 생산하여 방사선 계측/감시 분야를 비롯한 다양한 연구개발 목적에 활용하고 있다.

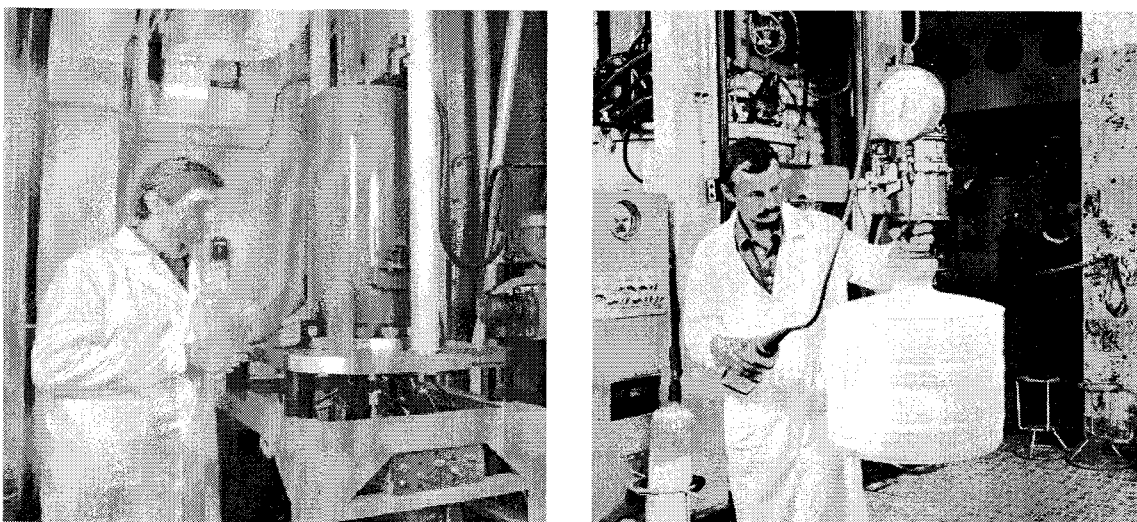


그림 4. ISC의 CZT 결정성장 자동화 시스템과 대규모 결정성장 시스템

한편, 저비용 물질을 이용하여 대규모의 고순도 사파이어 단결정 제작 기술을 개발하여 1993년부터 의료용 메스를 제작, 판매하고 있다. 최근에는 고온에서 단결정 물질을 소성 변형시켜 직경 700mm 이상의 대규모 단결정체를 제작하는 기술을 개발하고 이를 이용해 의료용 컴퓨터 방사선 단층 촬영기기를 개발, 제작하고 있다.

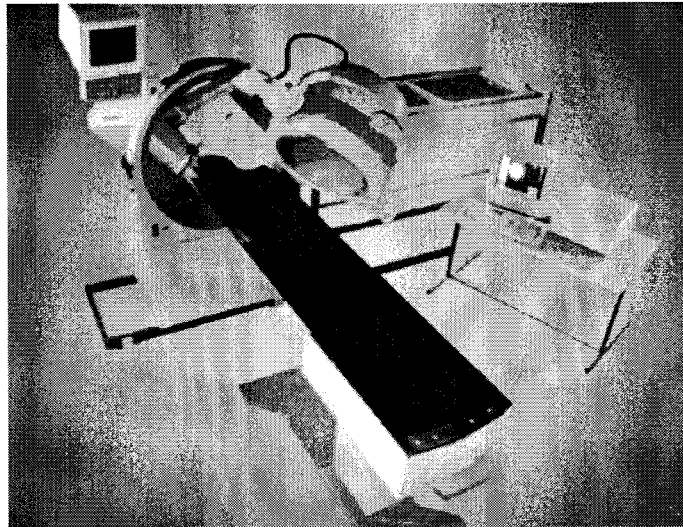


그림 5. 컴퓨터 방사선 단층 촬영기기 (ISC)

액정 물질(Liquid Crystals)을 이용한 생체조직등가 시스템 개발 연구가 현재 활발히 수행되고 있다. 생체조직등가 물질을 이용하여 방사선 계측기를 개발할 경우 기존의 여러 환산인자들을 적용하지 않고 곧바로 인체에 대한 방사선 선량을 측정, 평가할 수 있어 매우 획기적인 방법으로 평가받고 있다. 한편, 이와 관련된 연구들은 도시메트리 분야는 물론 일반적인 분자생물학이나 생물물리학 등의 분야에서도 매우 중요한 결과로서 평가받고 있다.

PMP(종사자 1,400여명)는 최근 세계적으로 각광을 받고 있는 CZT, CdTe에 대한 결정성장 및 상용화 기술을 보유하고 있다. 이 센서들은 100기압의 High Pressure Bridgeman 방법을 사용하여 방사선에 대한 검출 효율을 높임과 동시에 분해능이 우수하고 상온에서 동작하는 II-VI 화합물 반도체 검출기의 센서로 사용되고 있다. PMP는 주로 Si Ingot과 Wafer를 생산하고 있는 플랜트로서 반도체 재료, IR 센서 재료용으로 사

용되는 GaAs, CdTe, CZT 등의 화합물 반도체 생산 시설을 갖추고 있다. 방사선 계측기용 소재는 다른 생산라인에 비해 소량 생산되고 있으며 생산하는 상용화 CZT 소재의 크기는 Spectroscopic Grade는 아니고 단순 Detector Grade 수준인 5mm×5mm×2.5mm 로서 밝혀졌다.

제 2 절 국제협력 기반 및 연구 네트워크 구축

1. 한·우크라이나 전문가 초청 Joint 국제 세미나 개최

국제협력 지지기반 조성 및 기술인력 간 연구 네트워크를 구축하기 위하여 양국의 섬광형 방사선 계측기술 관련 전문가들을 초청하여 한·우크라이나 간 Joint 국제 세미나를 2003년 1월과 10월 2회에 걸쳐 한국과 우크라이나에서 각각 개최하였다. 표. 2에 한·우크라이나 간 Joint 세미나의 개요를 간단히 나타내었다.

표 2. 한·우크라이나 간 Joint 국제 세미나 개요

제 1 회 한·우크라이나 간 Joint 국제 세미나

- 개최시기 및 장소 : 2003.1.24 (경주, 한국)
- 국내발표자 :
김용균 외 3명 발표 (GEM Detector Development for Digital Radiography)
- ISC발표자 :
Volodymyr 외 3명 발표 (Multienergy X-ray Radiography and Reconstruction of Atomic Number of Materials)

제 2 회 한·우크라이나 간 Joint 국제 세미나

- 개최시기 및 장소 : 2003.10.13-14 (하리코프, 우크라이나)
 - 국내발표자 :
김찬형 외 4명 발표 (Radiological Characterization of Metal Oxide Semiconductor Field Effect Transistor Dosimeters)
 - ISC발표자 :
Eugen Pirogov 외 5명 발표 (Recent Investigations of Complex Oxide Scintillators)
-



그림 6. Joint 세미나 개최 (우크라이나)

우크라이나에서 개최된 한 · 우크라이나 Joint 국제세미나(그림 6)에서 한국(5명)과 우크라이나(6명)의 연구원들은 현재 양국에서 진행 중인 섬광형 계측기 관련 연구를 소개함으로써 정보를 교환하였다.

표 3. 우크라이나와 공동 출간하기로 합의된 저서의 목차

제목: Scintillator Crystals Radiation Detectors Based on Them
<p>Part 1. Scintillators</p> <hr/> <p>Chapter 1. Alkali halide crystals Chapter 2. Single crystals of complex oxides Chapter 3. Scintillators on the basis of semiconductor compounds</p> <p>Part 2. Scintillation Detectors</p> <hr/> <p>Chapter 4. Detectors scintillator-PMT Chapter 5. Scintielectronic detectors of scintillator-photodiode type (SELDI) Chapter 6. Integrated scintielectronic detectors</p>

2003년 1월 경주에서 개최된 Joint 세미나 기간 중 섬광형 방사선 계측기 관련 저서인 Scintillator Crystals Radiation Detectors Based on Them를 공동으로 출간하기로 합의하였으며 2004년도 초반 경 출간을 목표로 현재 출간업무가 진행 중이다.

ISC 연구소는 우크라이나에서 개최된 Joint 세미나 기간 중 발표된 섬광형 계측기 기술 관련 논문들을 Functional Materials지에(그림 7) 게재하기로 하였다. Functional Materials 지는 1994년에 설립되어 ISC에서 발간되고 있으며 Organic, Non-organic Functional Material의 이론 및 실용적 활용을 위한 연구부문에서 세계적으로 널리 알려진 저명한 Academic 저널이다.

한편, Joint 국제 세미나 기간 중 한 · 우크라이나 공동기술협력 연구를 위한 협정서 교환이 있었다. 이는 2003년 11월경에 새로이 신설된 우크라이나의 Technological Parks of Ukraine에 참여하는 첫 국제협력 사례이다.

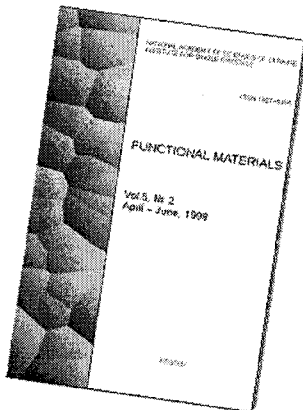


그림 7. Function Materials Journal



그림 8. 한 · 우크라이나 공동기술협력 연구를 위한 협정서 교환

2. ISC 연구원 2명 초청 세미나 개최

ISC 연구소내 섬광형 계측기 관련 전문가(Dr. Gektin, Dr. Ryzhykov) 2인을 초청하여 전문가 초청 세미나를 개최하였다. 세미나 주제는 섬광체 방사선 센서 개발과 X-선 검색장비와 관련된 내용이었으며 각각 'Recent

Developments in Scintillator Technology and Applications to Radiation Engineering’ 와 ‘Scanning Inspection System Based on Digital Radiography - Principle New Type Instruments for Radiation Control’ 란 제목으로 세미나를 개최하였다.

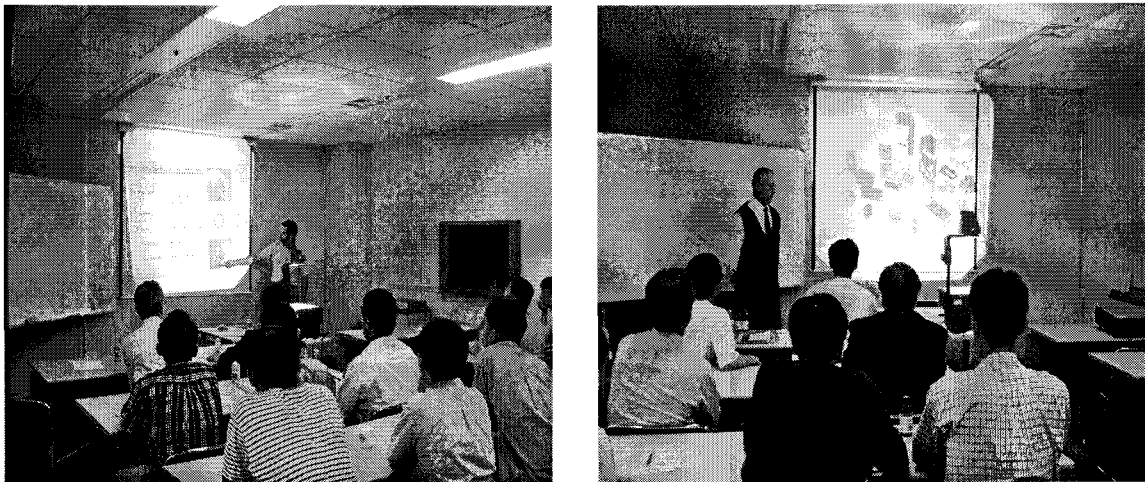


그림 9. Dr. Gektin 과 Dr. Ryzhykov 초청 세미나

제 3 절 핵심기술 확보를 위한 국제협력방안 마련

섬광형 계측기 기술 관련 핵심 기술은 CsI(Tl), BGO, CWO, GSO, ZnSe 섬광체 단결정 제작 기술과 CZT, CdTe 화합물 반도체 제작 기술 등으로 평가되며 이러한 기술은 향후에도 상당기간 시장성이 있을 것으로 평가되었다. 우크라이나 ISC 연구소는 세계적 수준의 섬광체 단결정 기술, 화합물 반도체 소재기술을 확보하고 있어, 한·우크라이나 간 국제협력 활성화를 통해 우리나라가 이 기술을 단기간에 확보할 수 있도록 추진할 필요성이 있다.

KAERI는 상온 반도체 검출기를 개발하기 위해 GaAs, CZT, CdTe 같은 섬광체들의 특성연구를 진행시킬 예정이고, ISC 연구소나 PMP 플랜트에서는 이미 상온 반도체 검출기와 관련하여 CZT등 대부분 첨단 섬광체들에 대한 제작경험 및 개발 노하우를 갖고 있으며 국제공동연구 개발협력에도 적극적인 의지를 가지고 있으므로 우크라이나의 선진 기술을 습득하기 위한 적극적인 국제협력 프로그램 개발이 필요하다.

CsI(Tl), BGO, CWO, GSO, ZnSe 섬광체는 의료용, 산업용 방사선 영상 계측기(Gamma Camera, SPECT, PET, Digital Radiography)에 널리 사용되고 있다. 특히, 감마선 영상을 얻기 위한 고효율 방사선 센서로 활용성이 높으며 향후 국내에서도 방사선 영상 계측기 산업이 활성화될 것으로 예상되므로, 핵심 센서 기술의 자립이 필수적이다.

CZT는 상용화된 상온 반도체 계측센서로서 미국의 eV Products 회사에서 세계 시장을 선도하고 있으며 연 매출이 1억\$ 수준인 것으로 알려져 있다. CZT 대형 단결정 기술은 아직도 우크라이나에서 개발 중인 기술로서, 미래 방사선 계측기 기술관련 산업 활성화 및 막대한 경제효과를 고려하여 한·우크라이나 간 공동연구를 통하여 초기에 해당기술에 대한 우리나라의 기술수준을 향상시키고 나아가 기술자립을 확보하기 위한 노력이 반드시 필요하다. 또한, 방사선 계측기 소재 기술 개발을 수행하기 위해 국제공동연구 수행(‘차세대 계측기 사업단’을 구성), 우크라이나 과학자 초빙 활용 등의 방법을 원자력 연구 개발 사업 과제의 일환으로 추진하는 것이 바람직하다.

제 3 장 연구개발결과 활용방안

제 1 절 섬광형 방사선 계측기 관련 향후 전망

타 연구 산업과 비교하여 RT산업의 비중은 점차 확대되고 있는 추세이며 새로운 종류의 계측기 및 계측기 센서의 개발에 대한 필요성도 점차 증가되고 있는 실정이다. 방사선 계측기 관련 기술축적의 중요성이 점점 커지는 반면 기술이전의 장벽은 더욱더 높아지고 있는 것이 세계적인 추세이다.

선진국에서는 CZT, CdTe 등의 새로운 차세대 반도체 검출기 센서를 이용한 방사선 계측기 및 ZnSe(Te) 같은 고 분해능을 가진 첨단 방사선 계측기를 개발하기 위해 활발한 연구가 현재 진행 중이며, 이 기술을 활용한 새로운 응용 계측기 산업이 추진될 전망이다.

우리나라는 우크라이나와 국가 간 원자력 협력을 체결한 만큼 한·우크라이나 간 국제세미나의 정례화 및 양국 간 기술인력 및 정보 교류가 더욱 증대될 것이고, 이를 통해 방사선 계측기 분야도 연구 네트워크가 더욱 강화될 것이다. 본 연구결과는 이러한 일련의 기술 동향 파악 및 양국 간 국제 협력에 크게 기여할 것으로 기대된다.

제 2 절 개발결과의 전략적 활용방안

1. 국제협력기반 강화 및 연구인력 간 교류 강화방안

한·우크라이나 간 국제협력기반을 타 연구사업 까지 확대하기 위하여 현재의 Joint 국제 세미나의 정례화 및 확대 추진이 필요하다. 확대 방향은 Joint 국제 세미나를 Senior Researcher를 위한 세미나와 Young Scholar를 위한 세미나로 나누어 실시하거나 또는 소규모 국제학술대회로 육성해 나가는 것이 바람직하다.

Joint 국제 세미나 개최 외에, 한·우크라이나 간 전문가 인력교류의 정례화를 위해 매년 정기적으로 우리나라와 우크라이나 전문가 인력들이 상호 세미나 개최를 위해 양국을 방문하도록 함으로써 양국의 섬광형 방사선 계측기 기술 관련 선진 기술 및 핵심기술들에 대한 정보를 교류하고 기술

인력 간 연구 네트워크 강화에 활용될 수 있다.

2. 섬광형 방사선 계측기 관련 핵심기술 확보방안

우크라이나는 높은 기술력을 보유하고 있으며 기술협력에 대한 강력한 의지를 가지고 있다. 특히, 우리나라와는 이미 원자력협력 협정을 통해 국가 간 기술협력을 위한 좋은 발판을 마련한 바 있다. 그러나 우크라이나는 여전히 서방국가로의 기술유출에 대한 막연한 불안감을 가지고 있다.

우리나라에서 국제협력을 위한 정부차원의 구체적 프로그램을 우크라이나에 제시함으로써 막연한 불안감을 해소시키고 국제공동연구를 내실있게 진행시킨다면 섬광형 검출기 기술과 관련하여 경쟁력을 갖춘 첨단 기술들을 국제협력연구를 통해 비교적 저렴한 비용으로 얻을 수 있을 것이다. 또한, 이를 바탕으로 타 연구사업의 국제협력연구를 위한 발판을 제공할 수 있을 것이다.

섬광형 방사선 계측기와 관련하여 우크라이나 주요 연구소 전문가들을 정기적으로 초청 국내 세미나를 개최하여 선진 기술동향 및 핵심 기술 등을 파악할 필요가 있다. 이를 통해 우크라이나의 선진 기술 및 국내에 필요한 핵심 기술들에 대한 연관성 및 국제공동연구를 추진할 수 있는 기초 자료 및 기술인력 간 인프라를 구축할 수 있다.

국내 대학 및 연구소의 섬광형 계측기 관련 기술 인력을 수개월 이상 장기간 ISC 연구소 등에 파견하여 우크라이나의 선진 기술을 연구하고 우크라이나 전문가 그룹과의 국제협력지지 기반을 공고히 할 필요가 있다. 한편, 파견 연구 등을 통해 향후 시장성이 있는 연구 과제를 발굴하고 한·우크라이나 양국이 국제공동연구를 수행함으로써 상호 이익을 실현할 수 있는 정책의 뒷받침이 필요하다. 이런 면에서 이번 연구를 통하여 일부 핵심기술인 섬광체 단결정 제작 기술 및 화합물 반도체 소재기술, 대규모 결정성장 기술 등에 대해서는 국내 연구기관의 국제공동연구 필요성 및 가능성을 상호 확인하였다.

3. 기 구축된 국제협력기반을 통한 타 연구사업 지원 방안

섬광형 계측기 기술과 관련하여 Joint 국제 세미나, 전문가 초청 세미나,

연구인력 파견 등의 프로그램을 통해 한·우크라이나 기술인력 간 연구 네트워크 및 국제협력지지 기반이 상당부분 확충되었다. 향후 이러한 국제협력 지지기반을 발판으로 타 연구 사업에서는 보다 효과적으로 우크라이나와 협력 프로그램을 진행시킬 수 있다.

기 구축된 국제협력 지지기반을 효과적으로 활용하고 대 우크라이나 기술협력을 위한 전초기지로서 활용하기 위하여 현재 iTRS 연구소를 중심으로 설립되어 있는 현지 연구소 프로그램 등을 확대 강화시킬 필요가 있다.

현재 iTRS를 통해 운영 중인 현지 연구실 프로그램은 기존 파견 연구자의 연구 공간 확보 및 한정된 기술협력을 위한 두 연구기관의 대외창구 역할만을 담당하고 있다. 하지만 현재 운영 중인 현지 연구소 프로그램을 확대 개편하여 한·우크라이나 간 기술협력을 위한 상설 연락사무소로 활동할 수 있도록 지원한다면 기존에 구축된 기술인력 간 연구 네트워크 및 국제협력 지지기반을 그대로 활용할 수 있다. 또한, ISC 연구소로부터 좀더 적극적인 국제협력을 유도할 수 있다. 한편, 우크라이나에서 중요한 위치를 차지하고 있는 ISC 연구소와의 협력강화를 통해 협력이 필요한 우크라이나 내 다른 유사연구기관과의 새로운 협력기반도 비교적 손쉽게 구축할 수 있다.



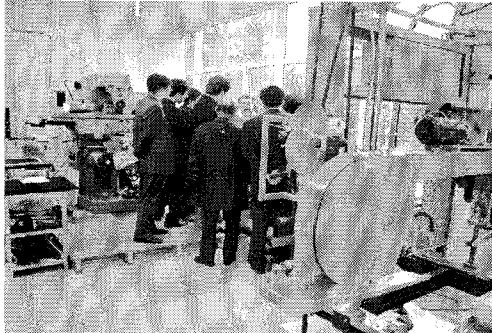
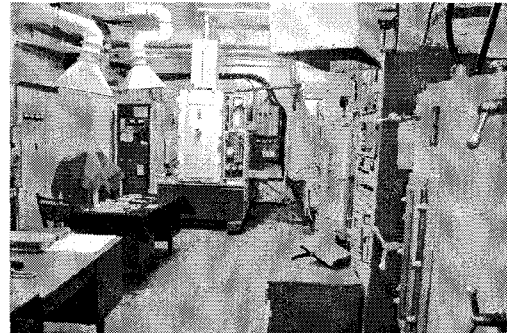
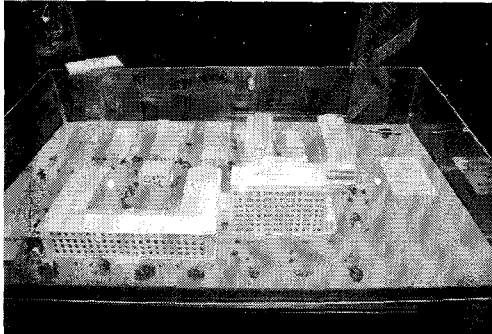

제 4 장 연구개발 과정에서 수집한 해외 과학기술정보




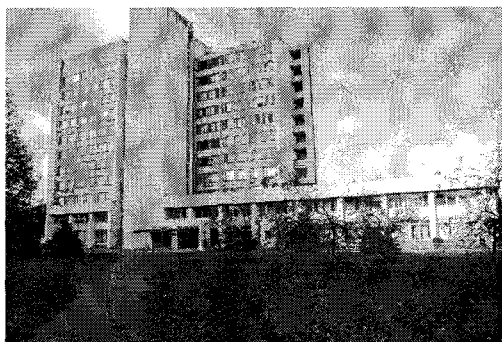
산·학·연 방사선 계측기 전문가 그룹의 우크라이나 주요 연구소 방문 등을 통해 방사선 이외의 분야에서 국제협력이 가능한 기술 분야 및 소재로서 ISC와 PMP에서 생산되고 있는 Optical Crystal, Piezo Crystal, Pure Metal 등의 기술협력 가능성을 확인 하였다.

또한, 의료목적에 주로 사용되는 Tc-99m과 관련하여 우크라이나의 KIPT(Kharkov Institute of Physics and Technology, 구 소련연방 3대 국책연구소중 하나임, 연구원 1,600여명) 연구소에서 현재 개발 중인 Electron Accelerator를 이용한 Tc-99m 생산기술 등이 개발 완료되어 국내 적용 시 매우 활용가치가 높은 기술로 판단된다.

한편, 현재 국내에서는 9.11테러를 기점으로 제기된 공항검색의 문제점을 해결하기 위하여 진보된 개념의 공항검색시스템 개발이 활발히 진행 중이다. ISC 연구소는 X-ray를 이용한 차량검색 및 자체 공항검색 시스템 등을 이미 구축하고 있는 상태이며 다양한 검색시스템에 대한 노하우 및 경험을 축적하고 있다. 기존의 국제협력 기반을 확장하여 이와 관련된 축적된 기술을 습득하기 위한 공동연구를 수행하는 것도 바람직하다고 판단된다.

부록 I. 우크라이나 주요연구소 방문 일정

October, 13:	
09:00 09:30	Meeting with ISC (Institute of Single Crystal) Management People
10:00 14:20	Attending the 한·우크라이나 Joint Seminar ◦ 세미나 진행: 김종경, Grinyov ◦ 국내 발표자: 김찬형, 김용균, 김재천, 배진형, 신형주 ◦ 국내 발표자의 발표 논문 중 4편을 Functional Material지에 게재하기로 함.
 	
16:00 18:00	Touring ISC Facilities ◦ ISC 연구소 전시장 투어 ◦ Czochralski Crystal Growing Furnace 시설 ◦ Gamma Camera용 Scintillator 가공시설 등
 	
 	

October, 14	
12:00 13:00	<p>Attending the World Bank Project Meeting Launched by the Center of Small Business Development Kharkov Technologies (Technology Business-Incubator)</p>
13:00 13:30	<p>Attending the Contract-Extension Signing Ceremony between iTRS and ISC</p> <ul style="list-style-type: none"> ○ 한/우크라이나 공동기술협력 연구를 위한 협정서 교환 (Technological Parks of Ukraine에 참여하는 첫 국제협력 시도사례) ○ 협정서 교환후 이를 축하하는 파티에 참석함.
<div style="display: flex; justify-content: space-around;">   </div>	
October, 15	
09:30 11:30	<p>Meeting with KIPT (Kharkov Institute of Physics and Technology) Management People</p> <ul style="list-style-type: none"> ○ 방사선 계측기 관련 기술의 타연구사업에서의 국제협력방안에 대해 한국의 산·학·연 전문가로 구성된 현장 방문팀과 KIPT 부소장 및 연구원들과 심도있는 회의를 개최. ○ 회의를 통해 Electron Accelerator를 이용한 Tc-99m 생산기술에 대한 국내활용성 및 국제협력 방안에 대해 검토.
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October, 16	
09:30 11:30	<p>Meeting with PMP(Pure Metal Plant) Management People</p> <ul style="list-style-type: none"> o 현장 방문팀 및 PMP플랜트 경영진과 방사선 계측기 기술 관련 CZT, CdTe, ZnSe(Ni) 등에 대한 국제협력 가능성에 대한 심도있는 회의를 거침.
	
13:00 15:30	<p>Meeting with IHEPNP (Institute of High Energy Physics and Nuclear Physics) Management People</p>

부록 Ⅱ. 출장결과 리포트 (강창순, 김용균)

Trip Report to Kharkov of Ukraine (강창순)

Itinerary of the Fourth Joint Seminar Between ISC and iTRS

October, 13:

09⁰⁰ 09³⁰ Meeting with ISC (Institute of Single Crystal) Management People

10⁰⁰ 14²⁰ Attending the Joint Seminar

16⁰⁰ 18⁰⁰ Touring ISC Facilities

October, 14

12⁰⁰ 13⁰⁰ Attending the World Bank Project Meeting launched by the Centre of Small Business Development "Kharkov Technologies" (technology business-incubator)

13⁰⁰ 13³⁰ Attending the Contract-Extension Signing Ceremony Between iTRS and ISC

October, 15

09³⁰ 11³⁰ Meeting with KIPT (Kharkov Institute of Physics and Technology) Management People

October, 13: Meeting with ISC

ISC Participants:

Professor Boris Grinyov: Director, Institute for Scintillation Materials, National Academy of Science of Ukraine

Professor Vladimir Ryzhikov: Director, Scientific-Technological Center of Radiation Instruments, Institute for Single Crystals, National Academy of Science of Ukraine

Dr. Valentin Chebanov: Academic Secretary, Institute for Single Crystals, National Academy of Science of Ukraine

Topics of Discussion:

Exploration of potential further cooperation between Ukraine and Korea in the areas of commercializing the high tech items that ISC has developed following the present successful cooperation between iTRS and ISC,.

October, 13: Attending the Joint Seminar

Chairs: Prof. Boris Grinyov (ISC), Prof. Joung Kyung Kim (iTRS)

Presentations:

1. Prof. Chan-Hyeong Kim "RADIOLOGICAL CHARACTERIZATION OF METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR DOSIMETERS"
2. Dr. Eugen Pirogov "RECENT INVESTIGATIONS OF COMPLEX OXIDE SCINTILLATORS"
3. Dr. Yong Kyun Kim "RADIATION DETECTOR DEVELOPMENT IN KAERI"
4. Dr. Serge Gordeev "LUMINESCENCE OF ZnSe(Te) EXCITED BY PLASMA LAYER OF INDIUM TIN OXIDE"
5. Mr. Jin Hyoung Bae "A MONTE CARLO STUDY OF CONTRABAND DETECTION USING FAST NEUTRON RESONANCE TECHNIQUE"
6. Miss Vlada Danilenko "PROPERTY UNIFORMITY STUDIES FOR ELEMENTS OF SCINTILLATION 1D- AND 2D-MATRICES MADE ON THE BASIS OF CRYSTALS ZnSe(Te), CdWO₄, CsI(Tl), Bi₃Ge₄O₁₂"
7. Mr. Jae Cheon Kim "ANALYSIS OF DESIGN CHARACTERISTICS OF THE PROTOTYPE IONIZATION CHAMBER AND BEAM LOSS MONITOR MADE BY KAERI"
8. Mr. Oleg Sidletskiy "Thermotropic liquid crystalline systems in bioEQUIVALENT DOSIMETRY"
9. Mr. Hyung Joo Shin "CODED APERTURE IMAGING FOR MONITORING THE NUCLEAR ENVIRONMENT"
10. Mr. Serge Sulima "GROWING OF CdZnTe SINGLE CRYSTALS AND REGISTRATION OF CHARGED PARTICLES BY A COMBINED DETECTOR ON THEIR BASIS"

October, 15: Meeting with KIPT

KIPT Participants:

Professor Ivan Karnaukhov: Vice-Director, Kharkov Institute of Physics and Technology, National Science Center

Professor Mykola Ayzatskiy: Deputy Director of Accelerator for Scientific Work, National Science Center, Kharkov Institute of Physics and Technology

Topics of Discussion:

Presentation of KIPT R&D activities by Professor Karnaukhov, and discussion of potential cooperation between Ukraine and Korea in the areas of advanced science and technology that KIPT has developed.

Conclusions and Recommendations:

1. The cooperation with the Institute of Single Crystal (ISC) on the development of Generation IV radiation detector materials could be a very attractive venture.
2. With the Kharkov Institute of Physics and Technology (KIPT), the utilization of electron accelerator in producing Tc-99m could be further pursued.

Based upon the conclusions, it is strongly recommended to form a task-force team, who should take a close look at the possibility of utilizing two technologies as follows:

- 1) With ISC, development of Generation IV radiation detector materials, and
- 2) With KIPT, utilization of electron accelerator in producing Tc-99m.

The decision should be made based upon the recommendations of the task-force team.

Ukraine 출장 보고 (김용균)

1. Institute of single crystal (mono crystal)

1.1 만난 사람

Prof. Boris Grinyov, 부소장

Prof. V. Ryzhikov

Prof. Longin Lysetskiy : ${}^6\text{Li}(\text{Eu})$, Stilbene, Anthracene
p-terphenyl for neutron detector

Dr. Sci. Vyacheslav Puzikov : CZT detector

Dr. Valentin A. Chebanov 등

1.2 iTRS-ISC 공동 세미나

iTRS측 5편, ISC측 5편 논문 발표

Program 참조

1.3 연구소 시설 견학

전시장 :

CsI, NaI, GSO, CWO, PWO 등 scintillator

CdZnTe detector,

Organic scintillator

Czochralski crystal growing furnace

Gamma camera용 scintillator 가공 시설

2. Institute of high energy physics and nuclear physics

2.1 만난 사람들

Prof. Dovbnya, Director of IHEPNP, Director of Accelerator 외

2.2 기술 협력 가능 분야

electron accelerator : 10MeV 10kW for sterilization

40MeV for medical isotope ${}^{99\text{m}}\text{Tc}$ production

Isotope separation

Plasma acceleration

Pure metal separation 5N or 6N

Radiation treatment of semiconductor

3. Pure metals plant

3.1 만난 사람들

Director Vladimir I. Komlach

Mayor Volodymyr M. Volkov

The first Deputy Mayor Hrigoriy Petrov

Prof. Yuriy M. Gavrylyuk

Prof. Anatoly P. Oksanich 등

3.2 협력 가능 기술 논의

- CdZnTe, CdTe 확보 시설 :

Vertical Bridgman furnace : 직경 40mm, 성장 기간 14일

Pressurize 가능 : 60기압

typical detector 5mm x 5mm x 2.5mm t

Cd_{1-x}Zn_xTe : x=0.04 ~ 0.1, 품질 균일성은 미확인

spectroscopic grade 불가, detector grade 상품화 가능

electric contact은 다른 lab.에서 함 : Indium contact

- ZnSe(Ni)

UV detector

UV-A, UV-B 자외선 분리 측정 가능 기술 필요

PMT 대체용 photodiode로의 활용 가능성 검토 필요

- GaAs : 제품 생산시설 및 기술 확보, 방사선센서로 활용은 어려움

- Silicon wafer : 판매 가능한 제품 생산,

- Pure metals : Ga, Cd, Te 6N (소개자료 참조)

- 필요 시설

Small clean room class 100

Crystal growing facility

Crystal 가공 장비 : Saw, Polisher

4. 공동 연구 개발 검토 의견

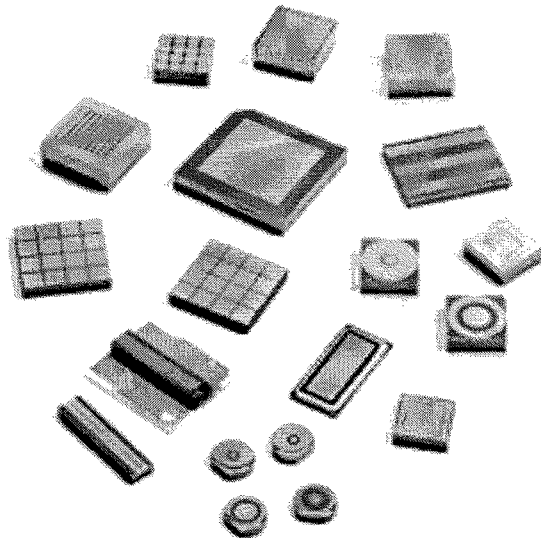
4.1 방사선 계측기

가. 우크라이나 기술 현황

- 우크라이나의 Institute of Single Crystal (ISC)는 방사선 계측 센서의 소재 분야에 있어 세계 최고 수준의 원천기술을 확보하고 있

는 것으로 평가된다. 특히 Alkali Halide 섬광체 (NaI, CsI 등), 복합 산화물 섬광체 (CdWO_4 , GSO, PWO, BGO) 단결정 제조 및 가공 기술이 우수하다.

- 방사선에 대한 검출 효율이 높으면서 분해능이 우수하고 상온에서 동작이 가능한 II-VI 화합물 반도체 검출기인 CdZnTe, CdTe의 결정 성장 기술도 확보하고 있는 것으로 평가되며, 100기압의 High pressure Bridgman 방법을 사용하고 있는 것으로 파악되었다. 그러나 관련 시설은 공개하지 않았다.
- Pure Metals Plant (PMP)는 주로 Si Ingot과 wafer를 생산하고 있는 기업으로서 GaAs, CdTe, CdZnTe 등 화합물 반도체 생산 시설도 갖추고 있다. 주로 반도체 재료, IR 센서 재료용인 것으로 생각되며, 방사선 계측기용 소재는 소량 생산되고 있다. 샘플로 전시되어 있는 방사선 계측용 CdZnTe 소재는 5mm x 5mm x 2.5mm t로서 spectroscopic grade는 아니고 단순 detector grade이다.



나. 공동 연구 제안

- 방사선 계측기 기술은 Radiation Technology (RT)의 핵심 요소 기술로서 방사선이 있는 곳에는 항상 방사선 계측기가 필요하다. 그러나 우리나라는 방사선 계측기 소재 및 센서 분야 기술이 취약하

여 대부분의 방사선 계측기를 선진국에서 거의 전량 수입하고 있다.

- 우크라이나는 세계적 수준의 섬광체 단결정 기술, 화합물 반도체 소재 기술을 확보하고 있으며, 국제 공동 연구를 통하여 우리나라가 이 기술을 단시간 내에 확보할 수 있도록 추진할 필요성이 있다.
- 목표 기술은 향후에도 시장성이 있는 것으로 평가되는 CsI(Tl), BGO, CWO, GSO, ZnSe 섬광체 단결정 제작 기술과 CdZnTe, CdTe 화합물 반도체 제작 기술이다.
- CsI(Tl), BGO, CWO, GSO, ZnSe 섬광체는 아직까지 의료용, 산업용 방사선 영상 계측기 (Gamma camera, SPECT, PET, Digital Radiography)에 사용되고 있으며, 특히 감마선 영상을 얻기 위한 고효율 방사선 센서로 활용성이 높다. 앞으로 국내에서도 방사선 영상 계측기 산업이 활성화될 것으로 예상되므로, 핵심 센서 기술의 자립이 필수적이다.
- CdZnTe는 상용화된 상온 반도체 계측센서로서 미국의 eV products 회사에서 세계 시장을 선도하고 있으며 연 매출이 1억\$ 수준인 것으로 알려져 있다. CdZnTe 대형 단결정 기술은 아직도 개발 중에 있으므로, 공동연구를 통하여 이 기술을 확보하는 것이 미래 방사선 계측기 기술 선도 및 산업 활성화에 반드시 필요하다.
- 국제 공동 연구 수행, 우크라이나 과학자 초빙 활용 등의 방법으로 '방사선 계측기 소재 기술 개발'을 원자력 연구 개발 사업 과제의 일환으로 추진하는 것이 바람직하다고 생각한다.

4.2 ^{99m}Tc generator

- 전자 가속기를 사용한 Tc 동위원소 생성량은 다음 그림에서 보는 바와 같이(Mo 표적은 Ag 근처 아래 질량임) 약 $Y(n/s/kW) = 1.5 \times 10^{12}$ 일 것으로 추정되므로 타당성이 있을 것으로 생각됨.

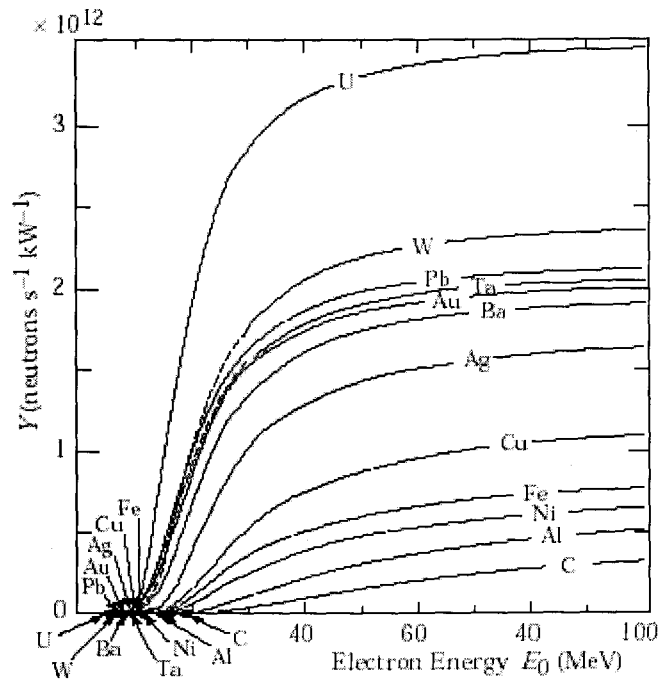


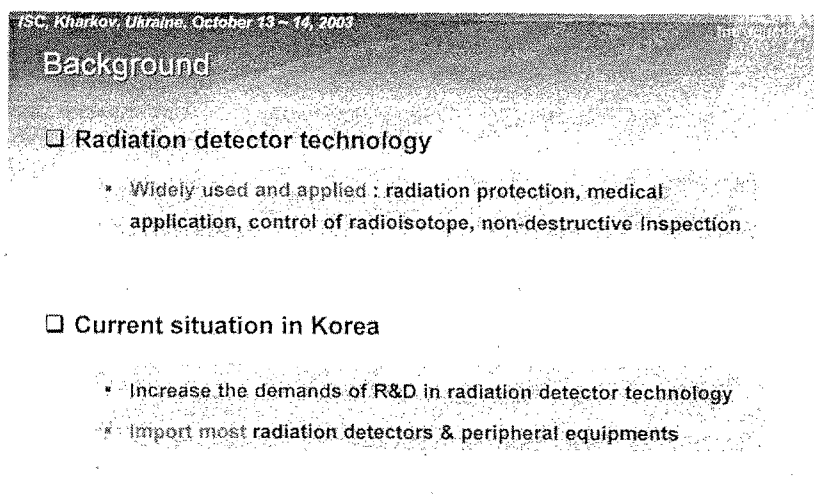
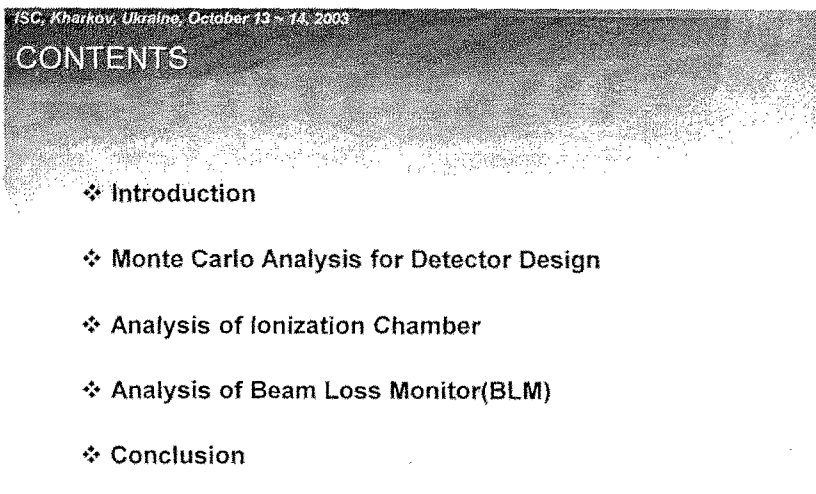
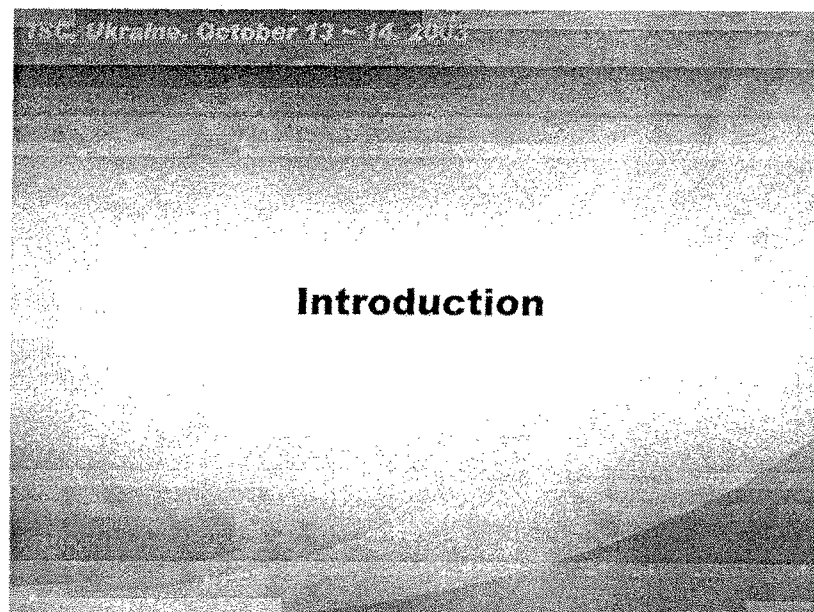
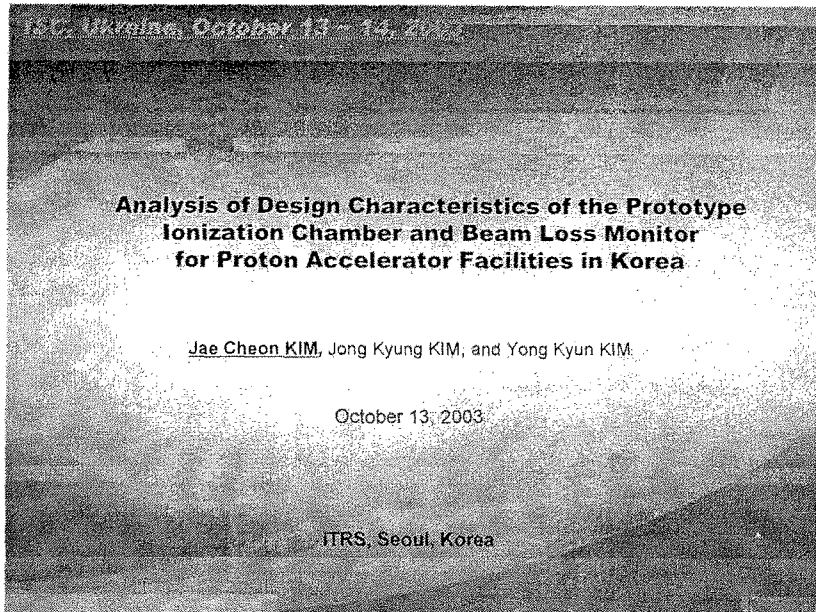
Figure 26.1: Neutron yields from semi-infinite targets, per kW of electron beam power, as a function of electron beam energy, disregarding target self-shielding.

* W.P. Swanson, Radiological Safety Aspects of the operation of Electron Linear Accelerators, IAEA Technical Reports Series No. 188 (1979).

4.3 기타

- 방사선 이외의 분야에서 활용 가능한 기술 및 소재로는 ISC와 PMP에서 생산되는 Optical crystal, Piezo Crystal, Pure metal 등이 국내 활용 가능성이 있는 것으로 생각됨.

부록 Ⅲ. Joint 국제세미나(우크라이나) 발표자료



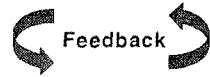
Objective & Procedure

Objective

- Establishing the analysis system for cylindrical ion chamber design (including BLM)

Procedure

- Design and analysis of the detector characteristics using Monte Carlo simulation



- Verification of the simulated results through experimental measurements

Simple Benchmark

EGSnrc & MCNP4C

- Used for electron /photon transport
- Used for detector analysis
- In 2000, included many improvement features

Benchmark calculation

- EGS4, EGSnrc, MCNP4B, MCNP4C
- Broad parallel electron beam (25keV ~ 4MeV)
- Semi-infinite water

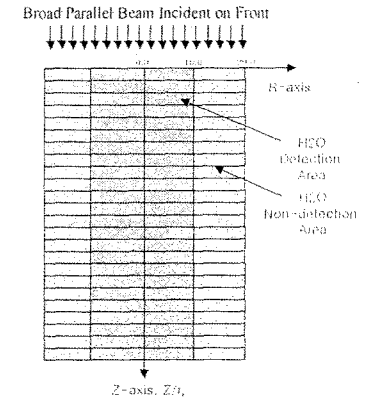


Fig. 1 Broad parallel electron beam incident on the semi-infinite water

Monte Carlo Analysis for Detector Design

Results (I)

Depth dose distribution (I)

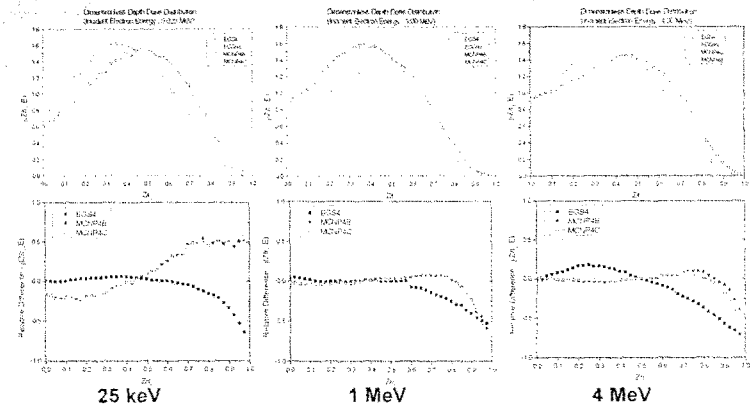


Fig. 2 Depth dose distribution of semi-infinite water

Results (II)

- Total absorbed dose in r_E
 - Absorbed dose of water : MCNP > EGSnrc, EGS4
 - MCNP4B & MCNP4C : about 0.04% (RMS)
 - EGS4 & EGSnrc : about 0.57% (RMS)

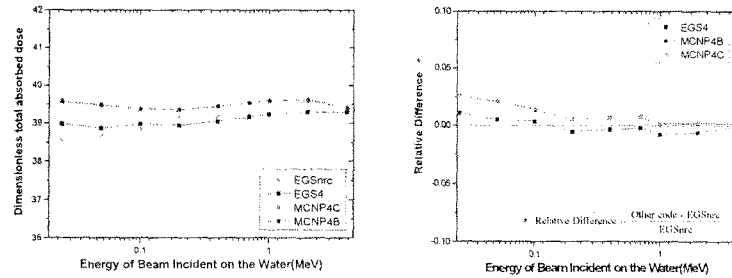


Fig. 3 The variation of the total absorbed dose in the semi-Infinite water

Design and fabrication

- Three types of ionization chamber
- Analysis of design characteristics
 - Energy linearity
 - Angular dependency
 - Variation of the length of collecting electrode

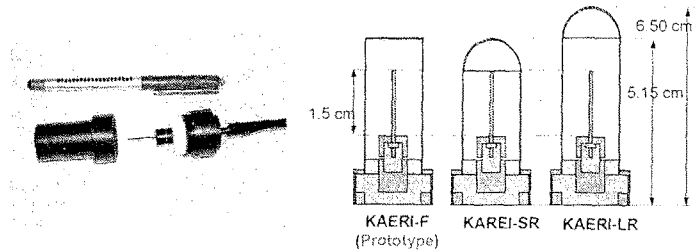
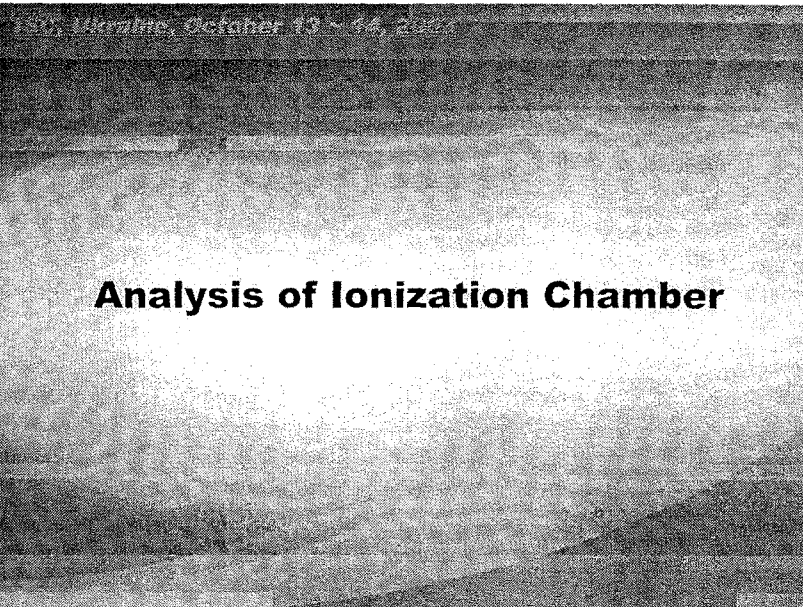


Fig. 4 The fabricated prototype ionization chamber having flat-type window

Fig. 5 Three types of ionization chambers designed and fabricated



Analysis of design characteristics (I)

- Energy linearity
 - Incident gamma-ray energy : 40keV ~ 1MeV
 - Current is linearly increased with incident gamma-ray energy
 - MCNP4C overestimated the dose compared with EGSnrc
 - KAERI-F : 7.2% (RMS)

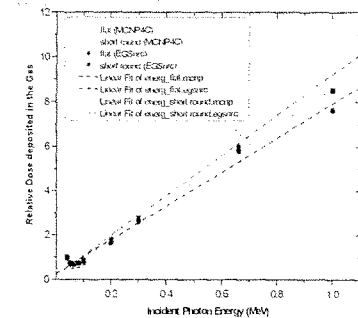


Fig. 6 Variation of the current according to changing incident gamma-rays from 40keV to 1MeV in KAERI-F and KAERI-SR

Analysis of design characteristics (II)

Angular Dependency

- Source : ^{241}Am , ^{137}Cs
- Incident source angle : $0^\circ \sim 90^\circ$
- Used normalized dose

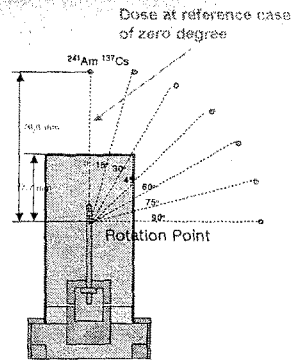
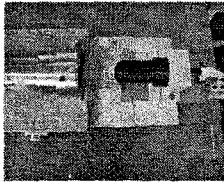


Fig. 7 The view of experiment that estimates the angular dependency of short round-type ionization chamber

Fig. 8 View of reference case and the rotation point in KAERI-F

Analysis of design characteristics (IV)

Defect of Modeling

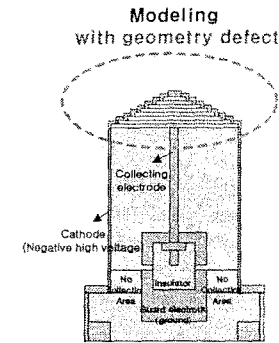


Fig. 10 Round-type ionization chamber modeled by EGSnrc

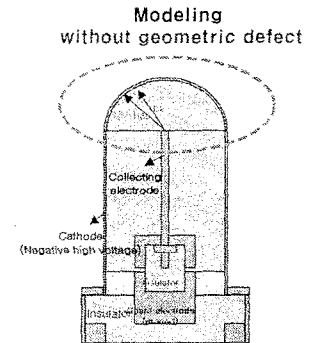


Fig. 11 Round-type ionization chamber modeled by MCNP4C

Analysis of design characteristics (III)

Simulation results

- KAERI-SR : less angle dependent than the others

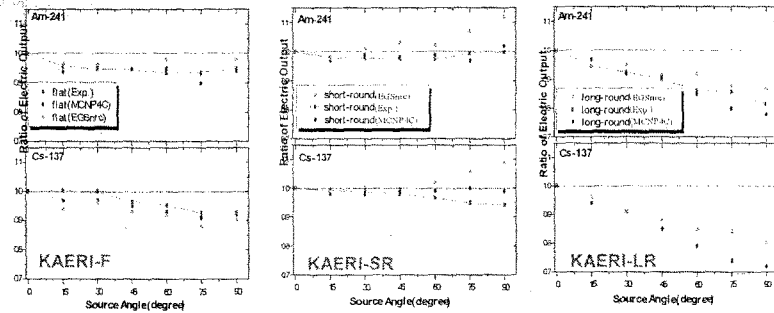


Fig. 9 The comparison between the doses of KAERI-F, KAERI-SR, and KAERI-LR by ^{241}Am and ^{137}Cs sources

Analysis of design characteristics (V)

Collecting Electrode

- Source : 1 MeV, 70 cm away from rotation point
- Original : 15 mm / Optimal : 12.5 mm
- Current difference is within 1%, negligible

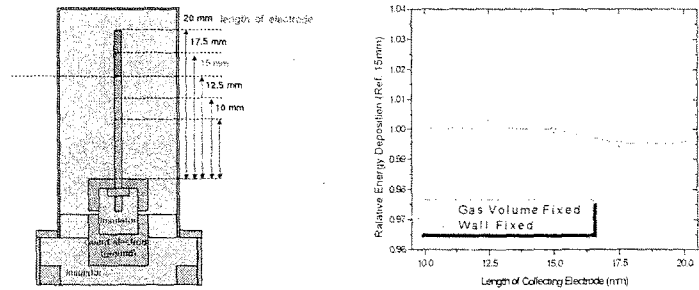


Fig. 12 The variation of the electric current according to changing the length of collecting electrode

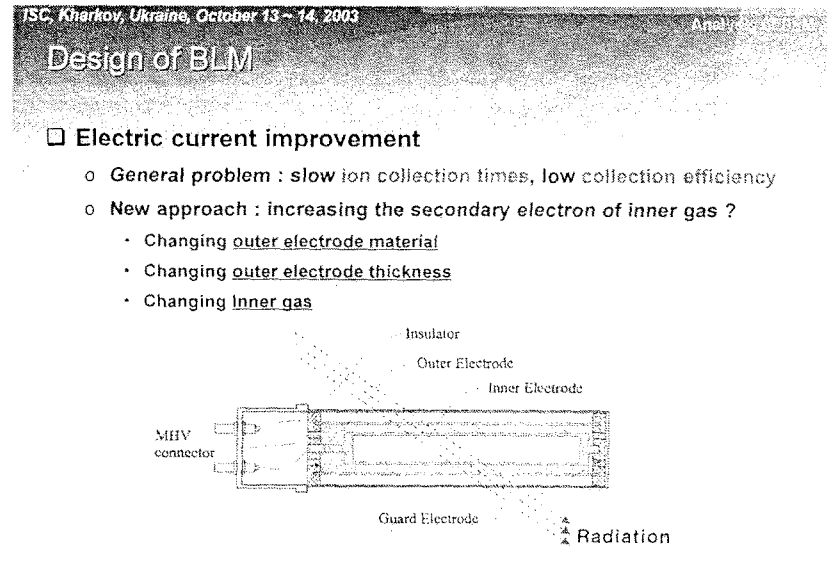
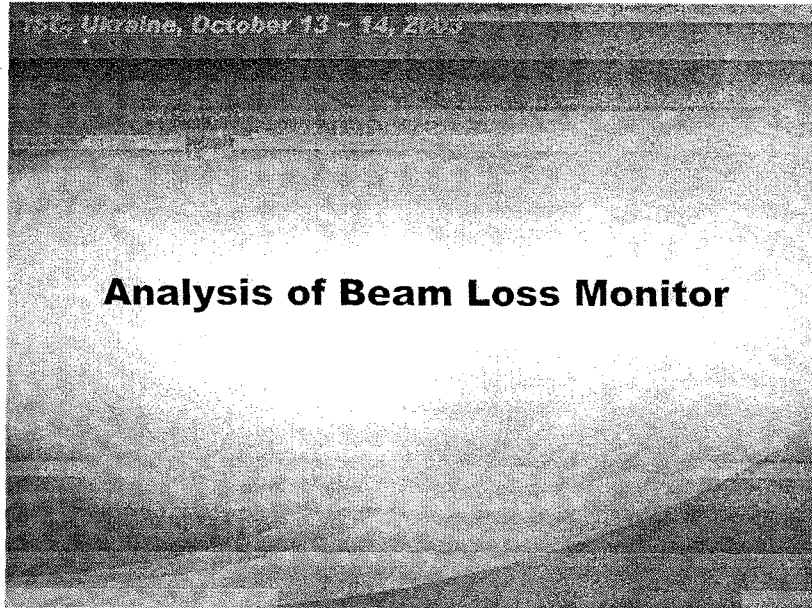


Fig. 14 Cross Sectional View of Beam Loss Monitor

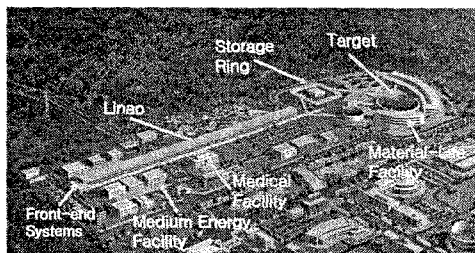
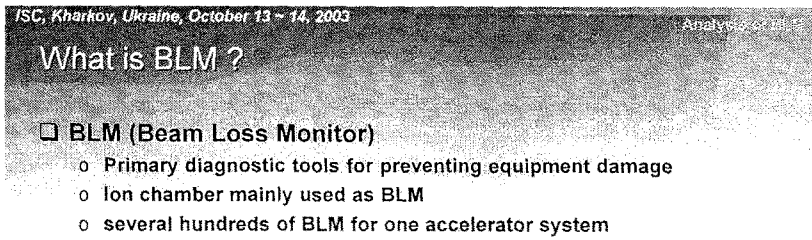


Fig. 13 The proton accelerator being developed in Korea

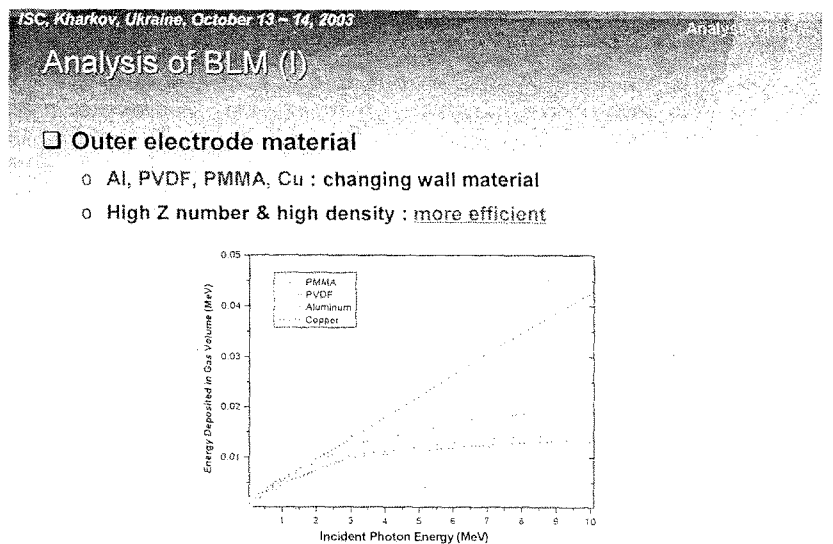


Fig. 15 Dose variation on the changing the wall material of BLM

Analysis of BLM (II)

Inner gas

- o Ne, Air, Ar, Xe : changing inner gas
- o Source : 1 MeV gamma-ray
- o High density & high Z number : more efficient

$$\text{Relative Dose} = \frac{\text{Dose of other gas} - \text{Dose of Ne-gas}}{\text{Dose of Ne-gas}}$$

Outer electrode thickness

- o Source : 1 MeV gamma-ray
- o Wall thickness :
 - PVDF: 2mm → 4mm
 - Difference is negligible (~1%)

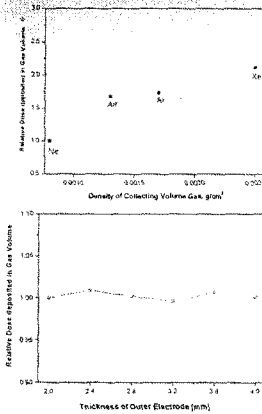


Fig. 16 Current variation by changing the inner gas and wall (outer electrode) thickness of BLM

Conclusions

Monte Carlo results for detector analysis

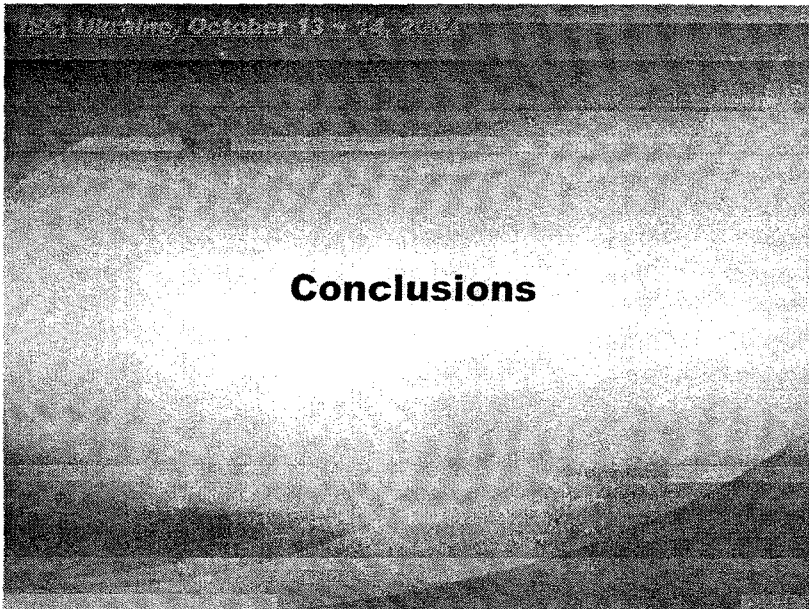
- MCNP > EGSnrc (in both gamma-ray and electron beam)
- EGSnrc : more drastic change compared with MCNP4C

Analysis of ionization chamber

- Energy linearity : linearly increases with gamma-ray energy
- Angular dependency : KAERI-SR, closest to sphere

Analysis of beam loss monitor

- Increase with density of wall material or its Z number
- Increase with density of inner gas material or its Z number
- Does not increase with thickness (for 1MeV, within 1%)



Coded Aperture Imaging for monitoring the nuclear environment

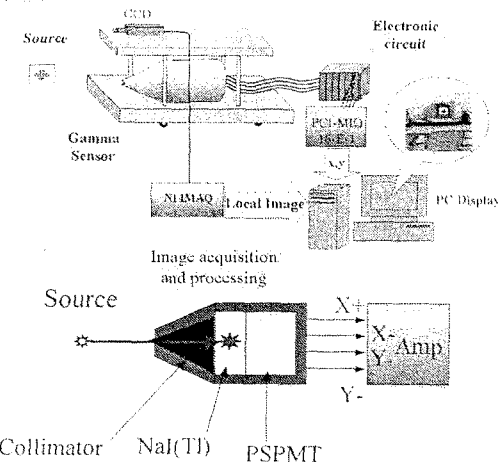
SHIN, HYUNG JOO & CHO, GYUSEONG
 Radiation Detection and Medical Imaging Lab.
 Department of Nuclear and Quantum Engineering
 Korea Advanced Institute of Science and Technology

Contents

1. Introduction
 - Gamma camera for monitoring the nuclear environment with the coded aperture
2. Coded aperture imaging
 - Concept
 - Mask pattern
 - SPSF
 - Simulation & Results
3. Discussion

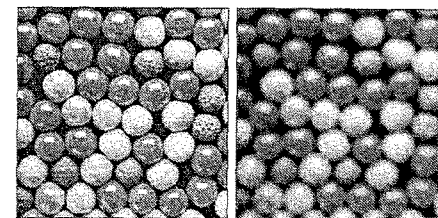
Introduction

- We had developed a gamma camera for monitoring the nuclear environment with a pinhole collimator and the pixellated scintillator
- We are going to replace the pinhole collimator with a coded aperture



Concept

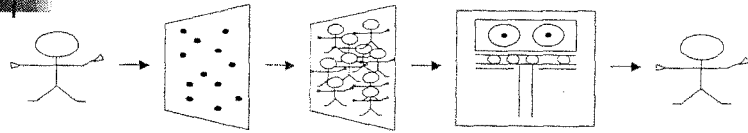
- Pinhole image has the high angular resolution, but sensitivity is very low.
- To collect more photons, we can make a hole bigger. However, the large hole reduces good angular resolution.



Two major motivations of coded aperture imaging :

1. We can improve the SNR in the reconstructed object by increasing the collecting area while maintaining the angular resolution of a small single opening.
2. We can perform tomography with a single exposure because object points at different distances from the aperture will cast shadows of the aperture onto the picture with different overall sizes.

Concept(2)



Object Aperture Encoding Decoding Reconstruction

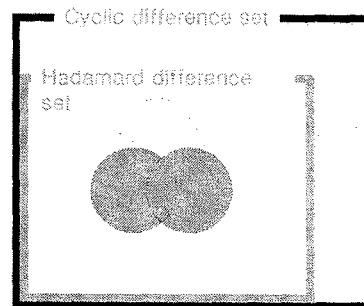
- The recorded image is not similar with the object at all because of many overlapping images during encoding.
- Nonetheless, if the aperture having good characteristic is judiciously chosen, the reconstruction image which is same as the object can be obtained.
 - $E = (O * A) + N$
 - $O' = E * G = RO * (A * G) + N * G$
 - If $A * G$ is a delta function, $O' = O + N * G$ and the object has been perfectly reconstructed except for the presence of the noise term.

How to locate the holes in the aperture(2)

- Cyclic difference set D
 - a collection of k integer numbers $\{I_1, I_2, \dots, I_k\}$ with values $0 \leq I_i < n$, such that for any $J \neq 0 \pmod{n}$ the congruence $I_i - I_j = J \pmod{n}$ has exactly z solution pairs (I_i, I_j) within D.
 - Can be represented by a binary sequence $a_i (i = 0, \dots, n-1)$ with $a_i = 1$ if i is a member of D and $a_i = 0$ otherwise.

How to locate the holes in the aperture

- Ideal aperture were found which are based on "cyclic difference sets"
- According to the value of n;
 - Quadratic residue sets (n is prime)
 - Twin prime sets ($n = p(p+2)$)
 - Pseudo-noise sets ($n = 2^m - 1$)



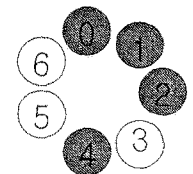
Some Hadamard difference sets may belong to more than one class.

How to locate the holes in the aperture(3)

Example

- $\{0,1,2,4\}$ is a cyclic set D with $n=7, k=4$ and $z=2$
- $\{0,1,2,4\} \Rightarrow \therefore a_i = 1110100$
- 1: transparent
0: opaque in a mask

- For J=1, $\{0,1\} \{1,2\}$
- For J=2, $\{0,2\} \{2,4\}$
- For J=3, $\{1,4\} \{4,0\}$
- For J=4, $\{0,4\} \{4,1\}$
- For J=5, $\{2,0\} \{4,2\}$
- For J=6, $\{1,0\} \{2,1\}$



How to locate the holes in the aperture(4)

From Fenimore and Cannon(1978 Applied Optics)

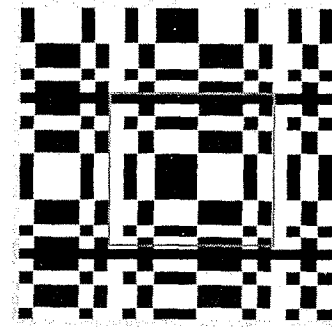
The basic array will have dimensions r by s where r and s are prime numbers.

$$A(i, j) = A(I, J), \text{ where } I = \text{mod}_r i \text{ and } J = \text{mod}_s j$$

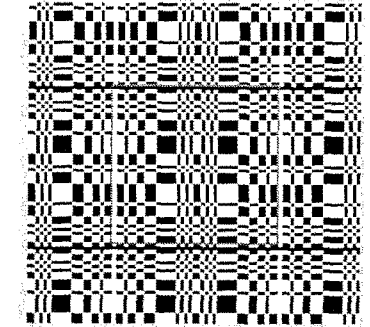
$$A(I, J) = \begin{cases} 0 & \text{if } I = 0, \\ 1 & \text{if } J = 0, I \neq 0, \\ 1 & \text{if } C_r(I)C_s(j) = 1, \\ 0 & \text{otherwise,} \end{cases}$$

$$\text{where } C_r(I) = \begin{cases} 1 & \text{if there exists an integer } x, 1 \leq x < r \\ & \text{such that } I = \text{mod}_r x^2 \\ -1 & \text{otherwise} \end{cases}$$

System Point Spread Function (SPSF)



13X11 URA



43X41 URA

How to locate the holes in the aperture(5)

- If we use postprocessing array G such as

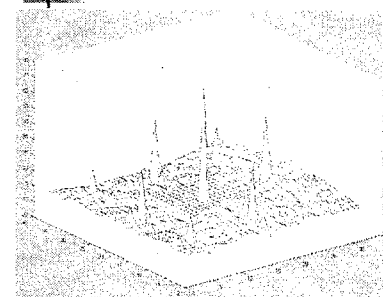
$$G(i, j) = \begin{cases} 1 & \text{if } A(i, j) = 1 \\ -1 & \text{if } A(i, j) = 0, \end{cases}$$

$$\sum_i \sum_j A(i, j)G(i+k, j+l) \propto (rs-1)/2 \quad \text{if } \text{mod}_r k = 0 \text{ and } \text{mod}_s l = 0$$

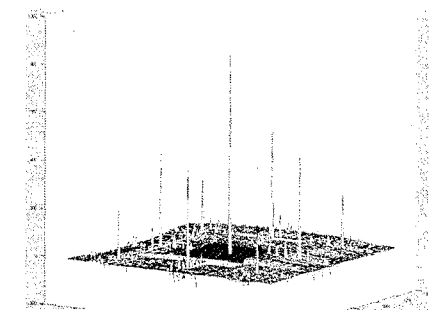
$$= 0 \quad \text{otherwise}$$

- These masks which are based upon the mathematical cyclic difference sets are generally referred to as uniformly redundant arrays. (URA)

System Point Spread Function (SPSF)(2)



13X11 URA

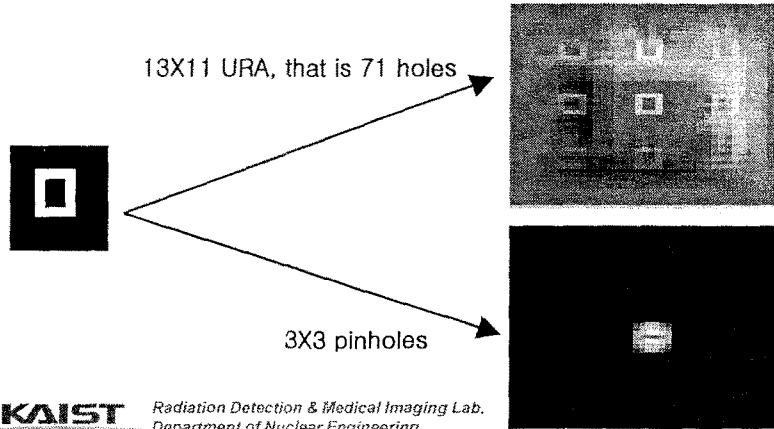


43X41 URA

- It is worthwhile to note that the correlation of A with G is a mosaic of delta function with zero sidelobes.

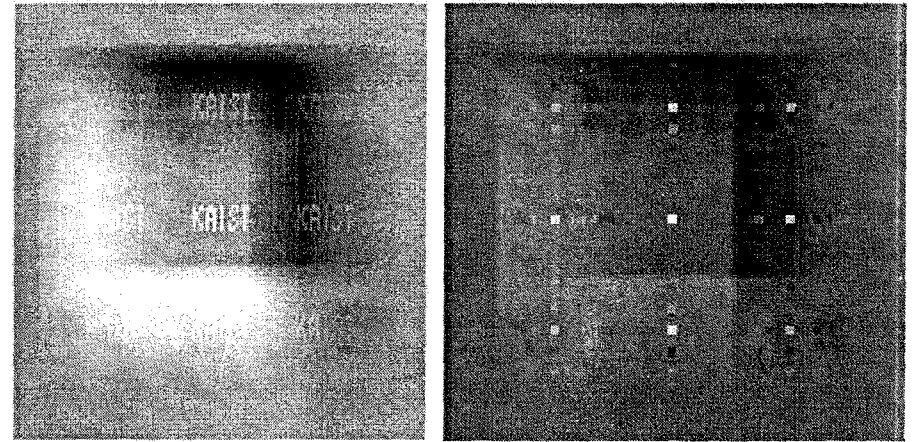
Simulation & Results

Pinholes vs. Coded Aperture



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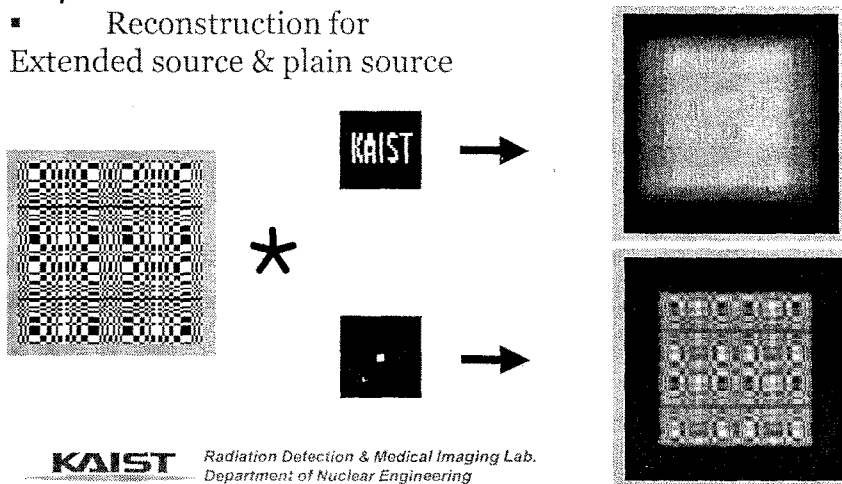
Simulation & Results(3)



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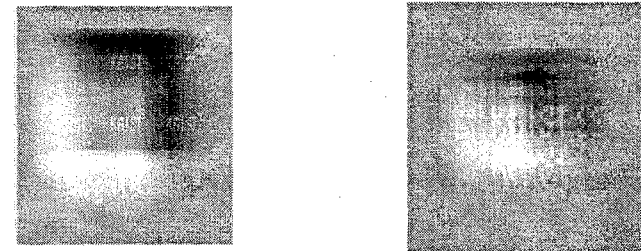
Simulation & Results(2)

Reconstruction for Extended source & plain source



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Simulation & Results (4)



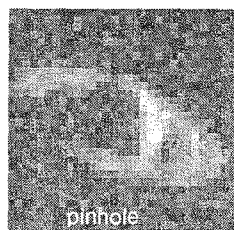
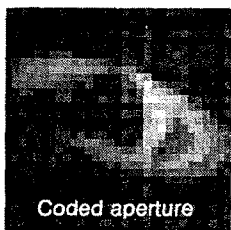
43X41 13X11

▪If the object becomes larger than basic aperture pattern, the different versions overlap. => the other factors can affect the geometric design. (eg. mask size, aperture size & depth, distance among source, mask, and detector, etc.)

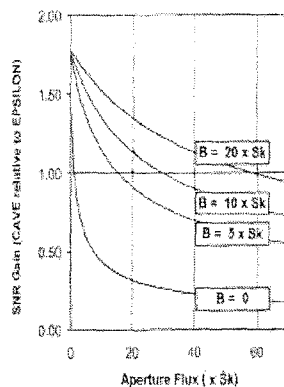
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Discussion

- It is known that for complex scenes or scenes where there is a high dynamic range and low background the pinhole is most appropriate whereas for high background environments the coded aperture would offer better sensitivity. (Durant,1999)



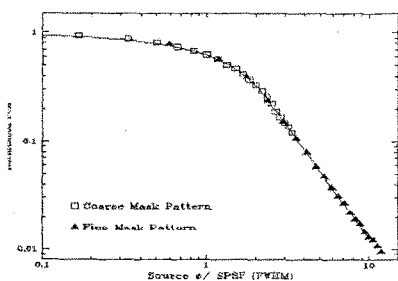
From Michigan



Discussion(3)

- Next steps..
 - Set up the instruments using the previous gamma camera and get experimental results
 - Simulate with consideration of activity
 - Optimize many interactive geometric design factors
 - Deeper study of reconstruction algorithm
 - Seek for better apertures

Discussion(2)



- As the source become comparable to the angular scale of the mask elements then there is an increasing loss in coded signal due to the increasing spillage of source events into background pixels.

Therefore, if we apply the coded aperture system to gamma camera system for monitoring the nuclear environment-high background and point-like source, we can expect the better performance.

***A Monte Carlo Study of
Contraband Detection
Using Fast Neutron Resonance Technique***

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Radioactive

Kyung-Hee University
Waste Laboratory



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- 1. Introduction
- 2. Fast Neutron Resonance Technique
 - Principle
 - Linear Attenuation Model
- 3. Neutron Energy Spectrum Calculation of Accelerator Target
for Fast Neutron Resonance Technique
 - Variable Energy Neutron Source & Deuteron Gas Target
 - Simulation of Deuteron Gas Target by DROSG-2000
- 4. MCNP Simulation of TNT Detection
 - Methods & Analysis
 - Conclusions

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Introduction

- Many of the explosives-detection technologies that are based on x-ray techniques measure the x-ray attenuation of the materials that make up the baggage.
- The mechanisms primarily responsible for x-ray attenuation in materials at the x-ray energy ranges typically used by explosives-detection equipment are Compton scattering and photoelectric absorption.
 1. Multi-energy x-ray-based detection equipment suitable for distinguishing organic from inorganic materials and for measuring densities and effective atomic number semiquantitatively has been developed.
 2. Dual-energy CT(computed tomography) is capable of providing geometrical information, as well as information pertaining to both the physical density and the effective atomic number of a material.
 3. Other x-ray-based methods using high-energy photons(between 10 and 30 MeV) have been discussed in the literature(Hussein, 1992;Gozani, 1988).

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Introduction

- Fast neutron resonance technique(FNRT) was developed to provide useful supplemental information regarding contraband for materials at the molecular and atomic levels.
- The FNRT method has been successfully used to determine concentrations of H, C, N, and O in explosives and narcotics as compared to many other common materials.
- The FNRT method of detection is to measure an object's effective attenuation coefficients and total atomic content. In theory, contraband can be identified using those two pieces of information. Monte Carlo simulations are used to support the theoretical concept of the method. The feasibility of the technique is demonstrated by employing TNT.

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2. Fast Neutron Resonance Technique

Principle

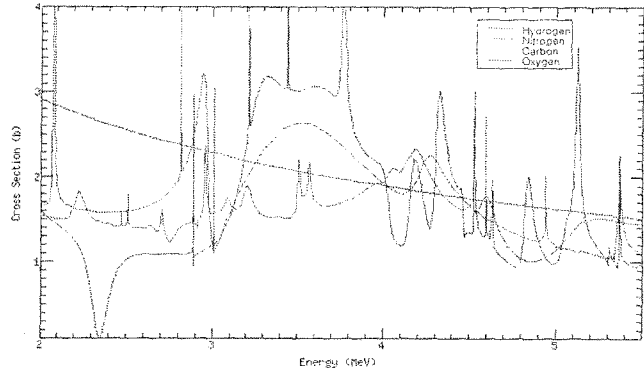


Figure 1. Total neutron cross section of H, C, N, O

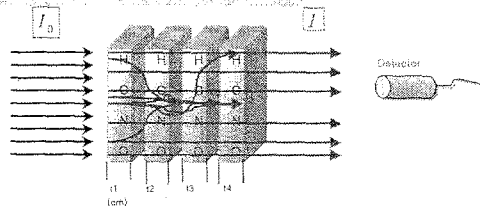
Continued

- With the presence of many elements, it becomes difficult to find distinct resonance peaks for all elements of interest.
- To improve the method, we turn to look at the broad resonance structure at neutron energy of 2-6 MeV, and introduce neutron resonance technique with broad peaks.
- Each element attenuates neutrons as if there were only this single element in the path, and that the total attenuation b is the sum of attenuation by all elements present. That is:

$$a_H x_H + a_C x_C + a_N x_N + a_O x_O + a_{other} x_{other} = b$$

2. Fast Neutron Resonance Technique

Linear Attenuation Model



$$I = I_0 \cdot e^{-\Sigma t} = I_0 \cdot e^{-N \sigma t} = I_0 \cdot e^{-\sigma t N} = I_0 \cdot e^{-ax}$$

$$\frac{I}{I_0} = e^{-ax} \quad \ln\left(\frac{I}{I_0}\right) = -ax \quad \ln\left(\frac{I_0}{I}\right) = ax$$

$$\rightarrow \Sigma a_i x_i = b$$

- I : neutrons transmitted through the sample
- I_0 : neutrons incident upon the sample
- a : effective attenuation coefficient (cm⁻¹)
- x : effective total atomic content (atoms/cm²)
- b : total attenuation

Continued

- The single equation stating that the total attenuation is the sum of attenuation by all elements is not sufficient to tell us the contents of any element. Thus, we need

$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \dots + a_{1j}x_j + \dots + a_{1n}x_n = b_1$$

$$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \dots + a_{2j}x_j + \dots + a_{2n}x_n = b_2$$

.....

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \dots + a_{ij}x_j + \dots + a_{in}x_n = b_i$$

.....

$$a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 + \dots + a_{mj}x_j + \dots + a_{mn}x_n = b_m$$

- Where b_i is the sum of attenuation by all elements at energy level i .

3. Neutron Energy Spectrum Calculation of Accelerator Target

Variable Energy Neutron Source

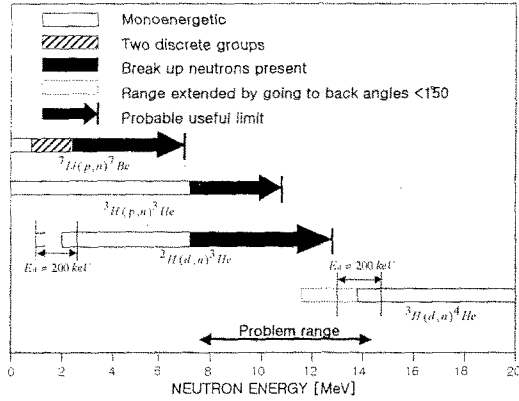


Figure 2. useful energy ranges of the "big-4" reactions

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3. Neutron Energy Spectrum Calculation of Accelerator Target

Rotational Geometry

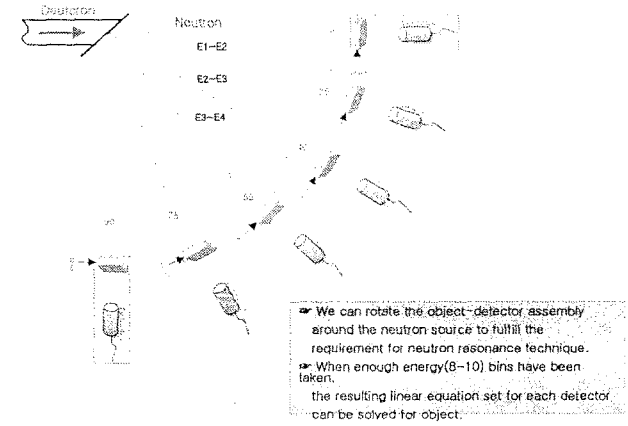


Figure 4. Rotational geometry

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3. Neutron Energy Spectrum Calculation of Accelerator Target

D-D Nuclear Reaction

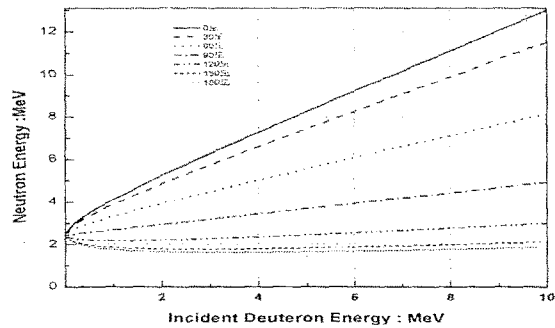


Figure 3. Reaction kinematics for $^2\text{H}(d,n)^3\text{He}$

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Continued

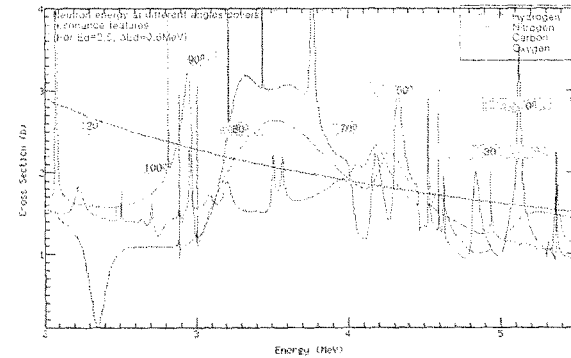


Figure 5. Neutron energy at different angles

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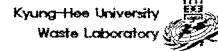
4. MCNP Simulation of TNT Detection

Atomic proportions of four HCNO compounds

Groups	#	Material	Atomic proportions			
			H	C	N	O
1	1	Ammonium nitrate	4	0	2	3
	2	C-4	16	8	11	11
	3	RDX/HMX	2	1	2	2
	4	EGDN	4	2	2	6
	5	PETN	8	5	4	12
	6	Nitrocellulose	7	6	3	10
	7	Nitroglycerine	5	3	3	9
	8	TNT	5	7	3	6
	9	Tetryl	5	7	5	8
	10	Picric acid	3	6	3	7
2	11	Heroin	20	17	1	1
	12	LSD	25	20	3	1
	13	Cocaine	21	17	1	4
	14	Morphine	19	17	1	3
	15	Mandrax	14	16	2	1
3	16	Paraffin wax	37	18	0	0
	17	Polyethylene	2	1	0	0
	18	Silk	13	8	5	4

* 1: explosives, 2: illicit drugs, 3: other materials
 (A. Butler et al. J. Nucl. Instr. And Meth. In Phys. Res. B 173 (2001) 483-502)

Radioactive



Continued

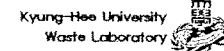
Table 1. Composition of TNT

	TNT(C ₇ H ₅ N ₃ O ₆)				Total
	H	C	N	O	
Mass Thickness (g/cm ²)	0.0358	0.6025	0.3013	0.6888	1.63
Atoms/ cm ²	9.31E19	1.60E21	7.83E20	1.79E21	4.32E21
Weight Fraction (%)	23.6	33.4	14.3	28.7	100

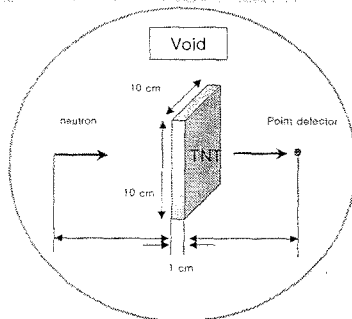
Table 2. Composition of TNT with covering materials

	TNT	Hexamine	Polypropylene(PP)
	(C ₇ H ₅ N ₃ O ₆)	(C ₆ H ₁₂ N ₄)	(C ₃ H ₄ O ₂)
Density(g/ cm ³)	1.63	1.331	0.9
Atoms/ cm ²	4.32E21	5.71E21	4.10E21

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Geometry of MCNP Simulation



- * TNT(mass fraction) : H(23.6%), C(33.4%), N(14.3%), O(28.7%)
- * Energy bins - total 12 bins
- * Good Geometry -- monobeam, point detector

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Continued

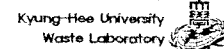
Table 3. Case of TNT with covering materials

Total # of elements	TNT	Al	Stainless Steel(SUS410)				
	H, C, N, O		Ni	Cr	Mn	Si	Fe
4						
5	*					
9	*	*	*	*	*	*
10	*	*	*	*	*	*

Table 4. Neutron energy bins used(in MeV)

Number of Energy Bins	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0	5.25
4	-	-										
5	-	-										
6	-	-	-									
7	-	-	-	-								
9	-	-	-	-	-							
10	-	-	-	-	-	-						
11	-	-	-	-	-	-	-					
12	-	-	-	-	-	-	-	-				

Radioactive



Continued

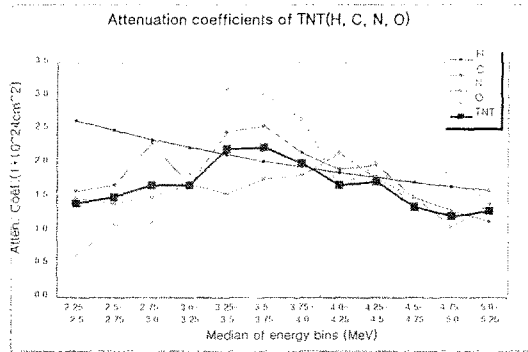


Figure 6. Attenuation coefficients of TNT(H, C, N, O)

4. MCNP Simulation of TNT Detection

Relative Error

$$error4 = \frac{\sqrt{(X_{SH} - X_{RH})^2 + (X_{SC} - X_{RC})^2 + (X_{SN} - X_{RN})^2 + (X_{SO} - X_{RO})^2}}{\sqrt{(X_{SH})^2 + (X_{SC})^2 + (X_{SN})^2 + (X_{SO})^2}}$$

error4, the relative vector error of (H, C, N, O)

error3, the relative vector error of (C, N, O)

Table 5. Properties and error4 of TNT

Thickness (cm)	Weight fraction(%)				Elemental ratios		Error4(%)
	H	C	N	O	C/O	N/O	
1	23.6	33.5	14.2	28.7	1.17	0.50	0.16
4	23.7	33.8	13.9	28.6	1.19	0.49	1.07
7	23.8	34.1	13.5	28.6	1.19	0.47	2.06
10	23.8	34.4	13.2	28.6	1.20	0.46	2.98
True value	23.6	33.4	14.3	28.7	1.16	0.50	*

4. MCNP Simulation of TNT Detection

Calculations of Linear Model

$$A = \begin{bmatrix} 2.6395 & 1.5901 & 1.4552 & 0.6307 \\ 2.4866 & 1.6750 & 1.4058 & 1.0843 \\ 2.3527 & 2.2965 & 1.4966 & 1.1205 \\ 2.2342 & 1.6806 & 1.6896 & 1.8442 \\ 2.1279 & 2.4829 & 1.5551 & 3.1158 \\ 2.0315 & 2.5608 & 1.7766 & 3.0412 \\ 1.9440 & 2.1599 & 1.8232 & 2.6824 \\ 1.8620 & 1.9151 & 2.1577 & 1.6409 \\ 1.7951 & 1.9796 & 1.7793 & 1.9979 \\ 1.7025 & 1.4945 & 1.5089 & 1.2991 \\ 1.6596 & 1.2995 & 1.0597 & 1.2500 \\ 1.6009 & 1.1369 & 1.3912 & 1.6081 \end{bmatrix}, \quad b = \begin{bmatrix} 0.1403 \\ 0.1503 \\ 0.1684 \\ 0.1678 \\ 0.2211 \\ 0.2229 \\ 0.1898 \\ 0.1684 \\ 0.1732 \\ 0.1353 \\ 0.1211 \\ 0.1286 \end{bmatrix}$$

$$A^{-1} = \begin{bmatrix} 0.3116 & 0.3260 & -0.1971 & 0.2637 & 0.1263 & -0.1246 & -0.0685 & -0.4316 & -0.2376 & -0.0667 & 0.2064 & 0.2206 \\ -0.1196 & -0.1299 & 0.8086 & -0.4781 & 0.0792 & 0.2695 & -0.0572 & 0.1216 & 0.1564 & -0.0439 & -0.1453 & -0.6191 \\ -0.0983 & -0.2175 & -0.2150 & 0.0730 & -0.4591 & -0.1997 & 0.0799 & 0.7283 & 0.2648 & 0.2523 & -0.1541 & 0.2100 \\ -0.0921 & 0.0059 & -0.3507 & 0.1632 & 0.2332 & 0.0809 & 0.1161 & -0.2365 & -0.0830 & -0.0631 & 0.0685 & 0.2390 \end{bmatrix}$$

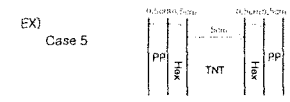
Four-constituent solution $x = (0.2362 \quad 0.3344 \quad 0.1423 \quad 0.2871)$,

and the true value is $x = (0.236 \quad 0.334 \quad 0.143 \quad 0.287)$

Continued

Table 6. Properties and error4 of TNT(5 cm), Hexamine and PP

Hexamine & PP Thickness (cm)	Four-constituent solution				Elemental ratios		Error4(%)
	H	C	N	O	C/O	N/O	
0.1	13.72	39.90	16.58	29.90	1.34	0.56	22.3
0.2	19.67	37.57	15.57	27.19	1.38	0.57	11.5
0.3	24.60	35.63	14.73	25.04	1.42	0.59	8.5
0.4	28.76	34.00	14.03	23.21	1.46	0.60	14.5
0.5	32.30	32.60	13.43	21.67	1.50	0.62	21.4
0.6	35.36	31.33	12.93	20.33	1.54	0.64	27.6
True value	23.6	33.4	14.3	28.7	1.16	0.50	*



Continued

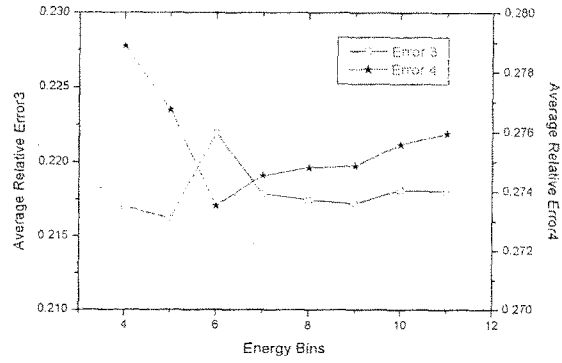


Figure 7. Error3 & Error4 of TNT(5cm), Hexamine and PP

Conclusions

- Fast neutrons from D-D reaction have a good spectrum of depending upon the angle from the target, which is very useful to detect materials consists of many elements.
- Various models with simple geometry have been simulated by MCNP
 - Linear Attenuation Model to FNRT is reliable.
 - The results encourages should be to go further.
- More studies to decrease the size of error occurring when the material in question exists with covering materials are required and the energy spectrum analysis will be performed.

Continued

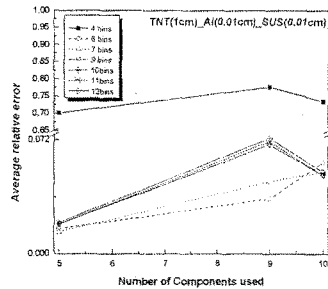


Figure 8. [C, N, O] error for various combinations of m and n

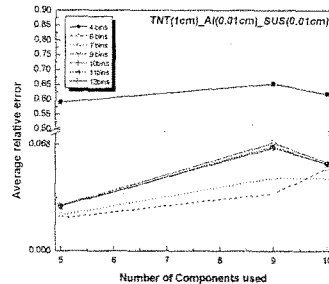
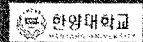


Figure 9. [H, C, N, O] error for various combinations of m and n

Radiological Characterization of Metal Oxide Semiconductor Field Effect Transistor (MOSFET) Dosimeter

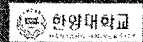
Chan-Hyeong Kim

Department of Nuclear Engineering
Hanyang University



Objective

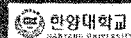
- To develop a 3D Monte Carlo simulation model of the MOSFET dosimeter



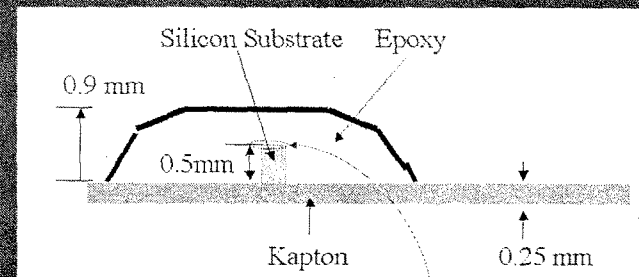
Introduction

M O S F E T

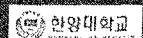
- Since 1974
- Widely used in space dosimetry, radiation therapy, and diagnostics
 - Small size
 - Immediate readout
 - Easy to use
- High-energy photons vs. low-energy photons



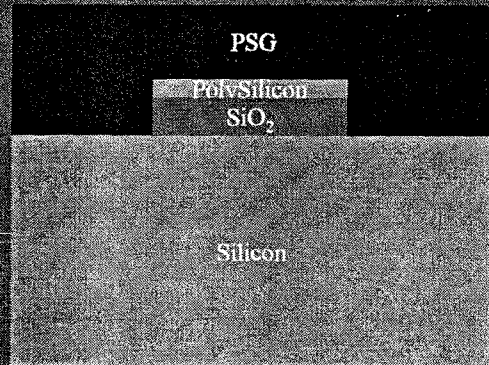
Schematic diagram of the MOSFET dosimeter



Sensitive volume



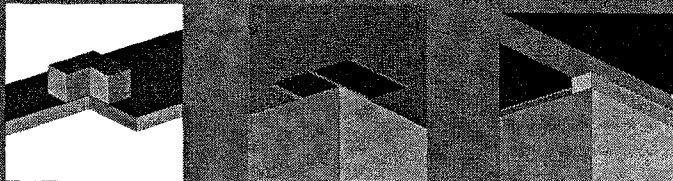
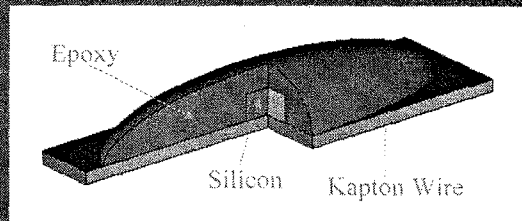
Schematic diagram of the sensitive volume



Problem?

- The sensitive region of the MOSFET dosimeter is very thin (1 micron) and causes problems in electron transport simulation.

3D model in MCNP

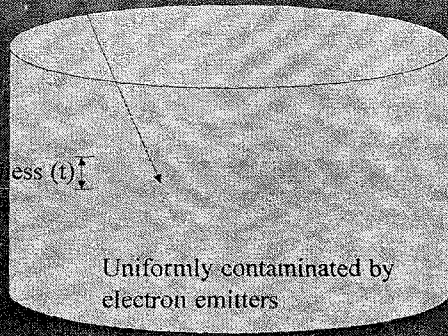


Prescriptions

1. Imparted energy directly from electron tracks (Dennis Schaart, 2002)
 - Electron fluence, $\Phi(E)$
 - "Modified" restrictive mass stopping power, $(S/\rho)_\Delta$
2. # of electrons substeps > 10
3. ITS energy indexing algorithm

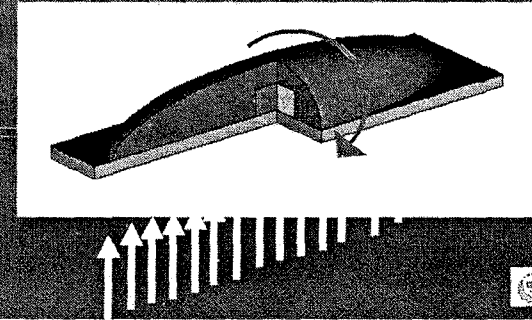
Validation of the proposed method

Tallying volume

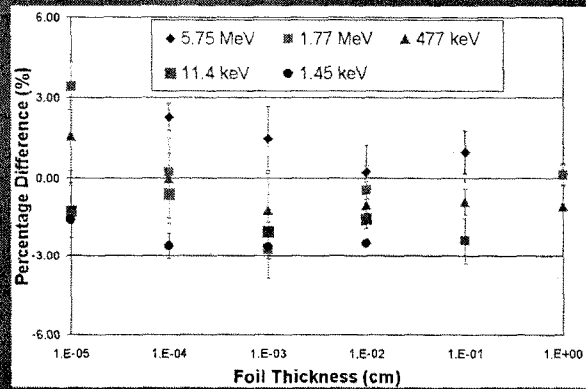


Comparison with measurement – angular dependence

- For ^{137}Cs (0.662 MeV) photon energy
- Rotated along the axis

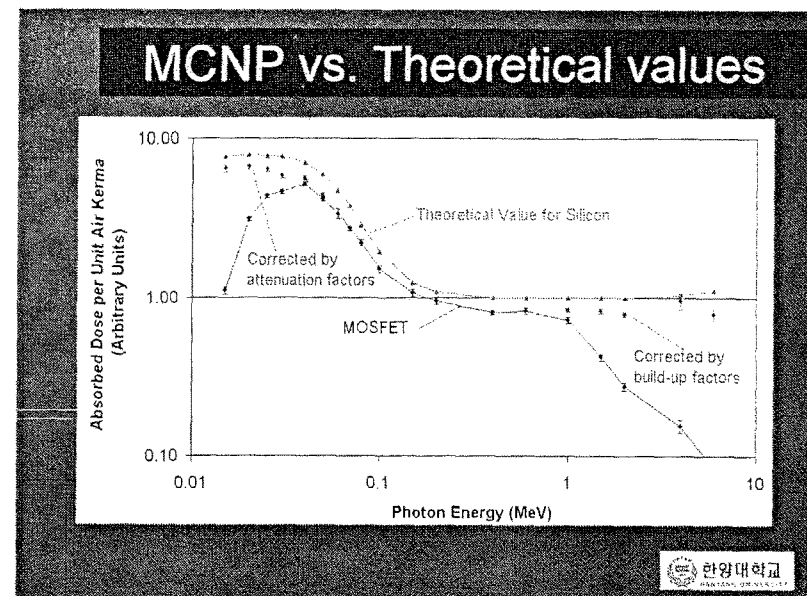
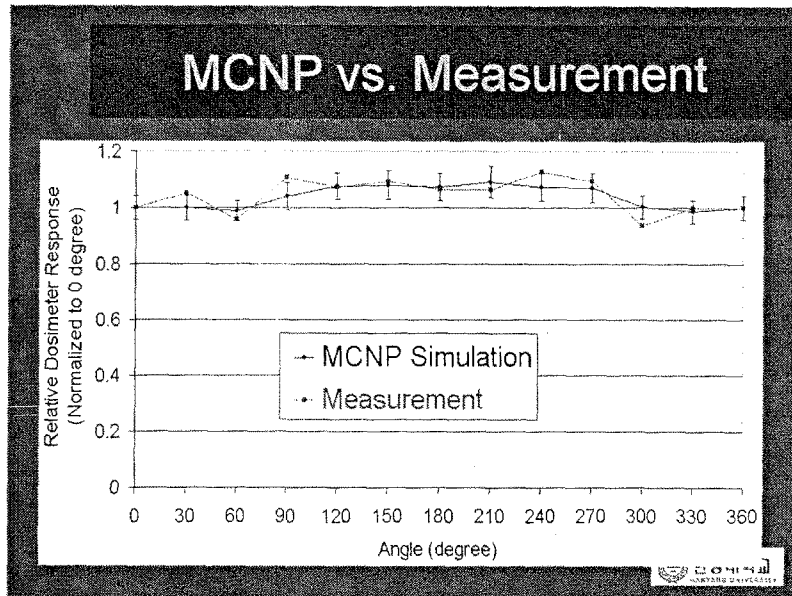


MCNP vs. Exact value



Measurement





Comparison with theoretical values – energy dependence

- Standard direction
- Monoenergetic, broad parallel beam
- 20 keV – 6 MeV

The diagram shows a cross-section of the dosimeter. From top to bottom, it consists of a Silicon Substrate (0.9 μm thick), an Epoxy layer (0.5 μm thick), and a Kapton layer (0.25 μm thick). A MOSFET is embedded in the silicon substrate. Arrows at the bottom indicate the direction of the incident photon beam.

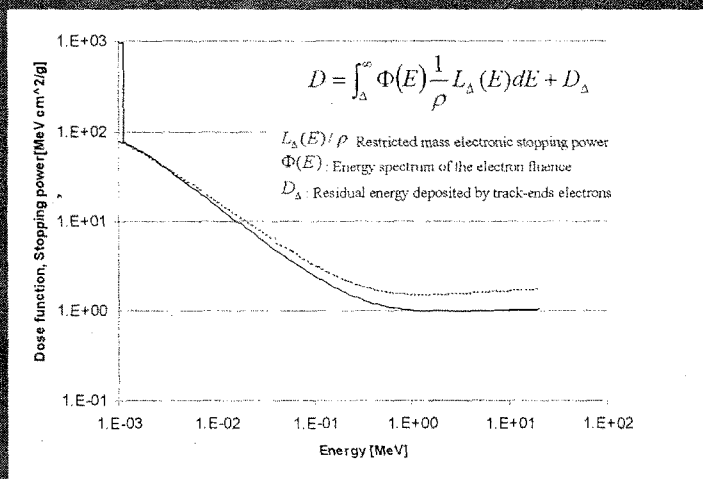
Conclusions

- A Monte Carlo model of the MOSFET dosimeter was developed.
- The developed model will be used to characterize the MOSFET dosimeter for low and medium energy photon applications.
 - Effective Dose Measurement System (EDMS)

Backup Slides



Modified Restrictive Mass Stopping Power



Radiation Detector Development in KAERI

2003. 10. 13.

Yong-Kyun Kim
Korea Atomic Energy Research Institute

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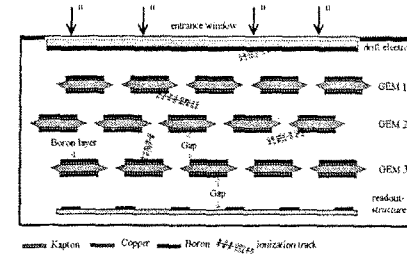
Contents

2

- Gas-filled detector development
 - GEM
 - Ion chamber
 - For radiation monitoring system (RMS)
 - For beam loss monitor (BLM)
- Scintillation detectors
- Solid state detectors
 - Si detector
 - CdZnTe or CdTe for new RMS

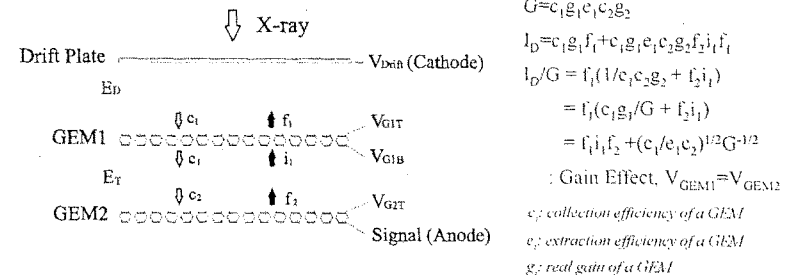
Research using GEM

- ◆ GEM Gas Photomultiplier:
 - narrow, independent multiplying channel
 - opacity to photon and ion feedback:
high gain with noble gas mixture
- ◆ GEM for neutron detector



Model of Ion Feedback

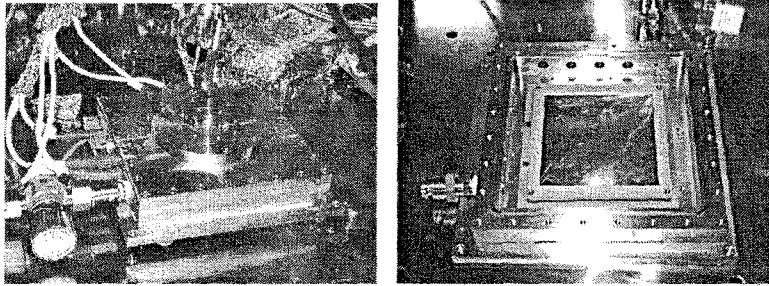
4



- Ion Feedback ratio can be understood from the charged particle transfer efficiency through a GEM.

Experimental Setup

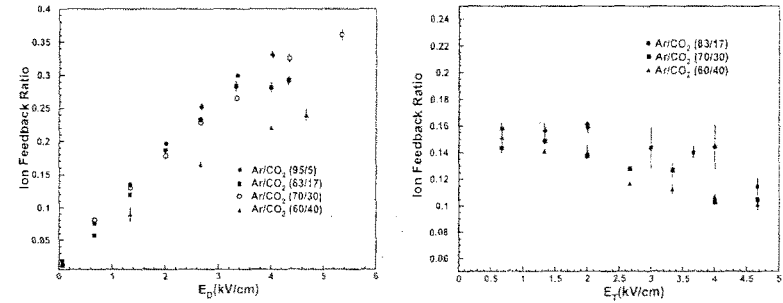
5



- Assembled stainless chamber with Be window(0.5 mm thick)
- Inside of chamber mounted with GEM detector

Drift Field, and Transfer Field Effect

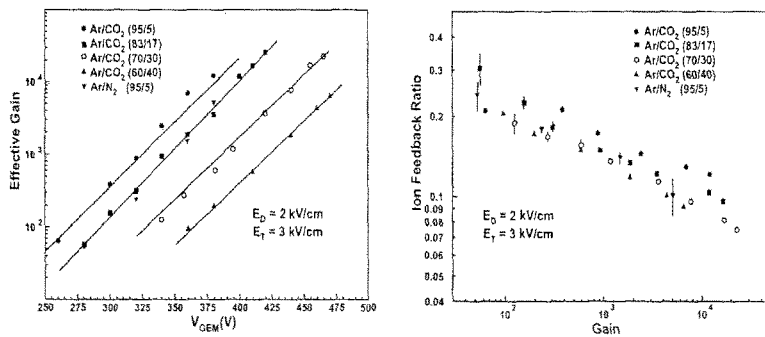
7



- Ion Feedback ratio is very sensitive to the Drift Field.
- Ion Feedback is almost independent to the Transfer field.

Gain, and Gas Mixture Effect

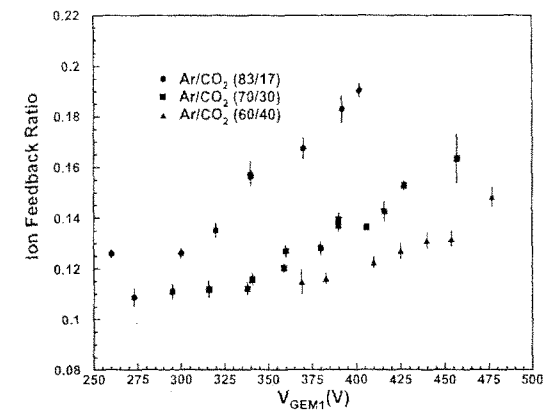
6



- Ion Feedback decreases with gain.
- Ion Feedback is independent of gas mixture(diffusion).

Asymmetry Effect

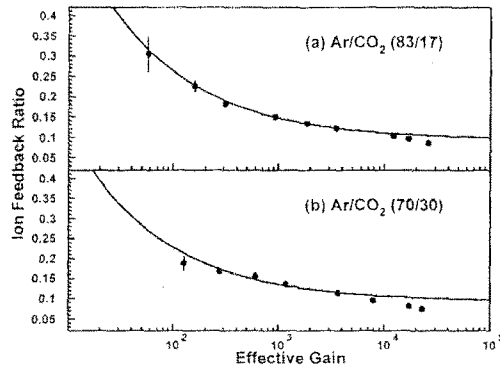
8



- Ion Feedback ratio becomes larger when V_{GEM1} is larger than V_{GEM2} .

Fitting with the Model

9



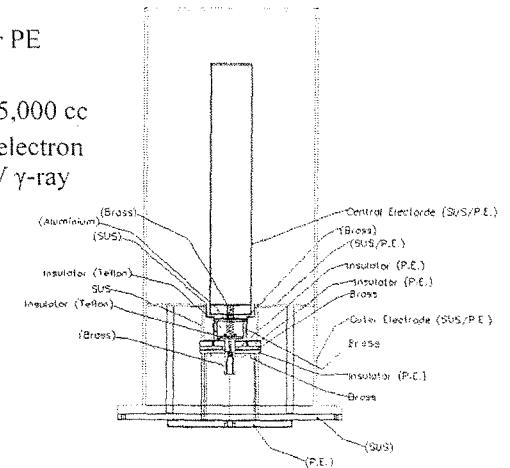
← $Y=a+b/x^{1/2}$ form

- Deviation from the model in higher gain could be understood from the avalanche extension.

Ion chamber for RMS

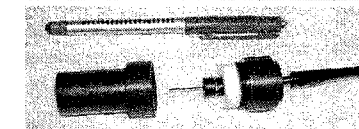
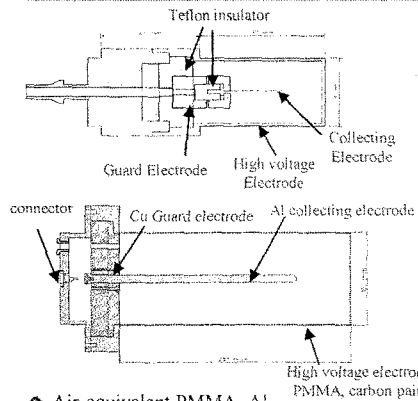
11

- Electrode : SS316L or PE
- Sealed gas : Ar, N₂
- Collecting volume : 25,000 cc
- Designed to consider electron equilibrium for 1 MeV γ -ray

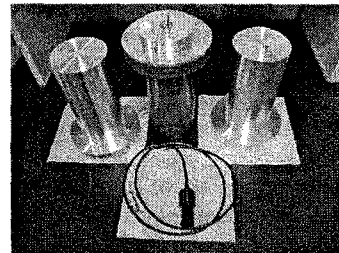


Ion Chamber

10



- Air-equivalent conductive plastic PVDF
- mechanically connected to triaxial cable
- collecting volume: 14.4 cm³

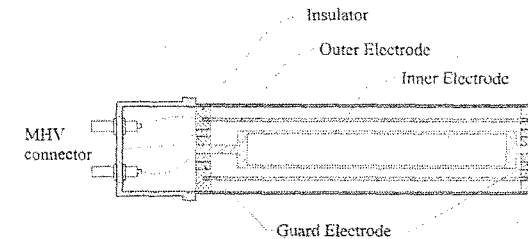


- Air-equivalent PMMA, Al
- Cylinder diameter 100mm, length 200mm
- Collecting electrode $\phi=8$ mm, $l=175$ mm
- Collecting volume: 1500 cm³

Beam Loss Monitor for HPA

12

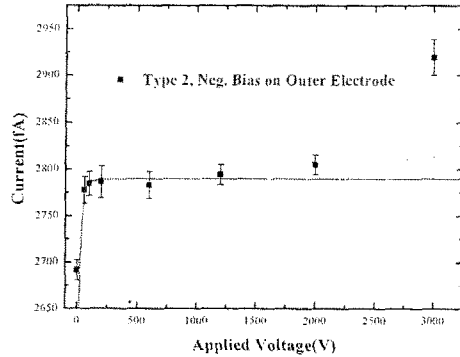
- ✦ BLM system is for
 1. the primary diagnostic tool for tuning
 2. Preventing excess activation and equipment damage.



- ✦ Filled with air.
- ✦ Diameter of outer electrode: 38 mm
- ✦ Inner electrode: diameter of 6 mm (Type 1), 16 mm (Type 2), 25 mm (Type 3)
- ✦ Inner Electrode, Outer Electrode: Al. Guard Electrode: Copper. Insulator: Teflon

Saturation Curve

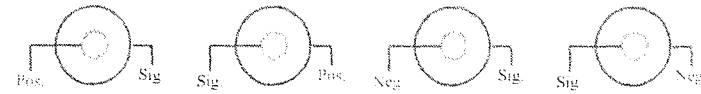
13



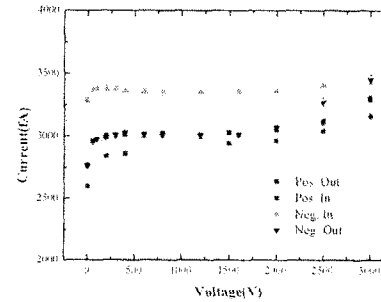
- High voltage: ORTEC Model 660
- Signal: Keithley 6517A Electrometer
- 60 keV γ -ray from ^{241}Am incident perpendicular to the cylinder surface.
- Measurement of the influence of Bias polarity.

High Voltage Bias Polarity

15



Four Bias and Signal Configuration

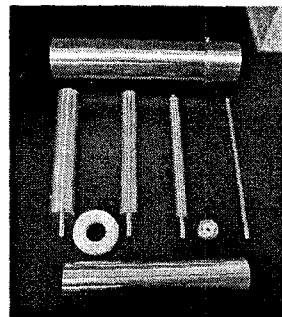
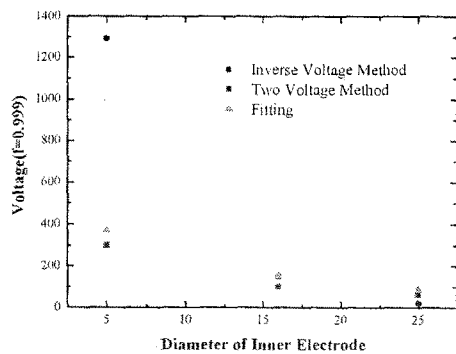


- When high voltage is biased on the outer electrode, magnitude of current is not changed with bias polarity.
- When high voltage is biased on the inner electrode, the magnitude of current is changed with bias polarity. (potential difference between guard and collecting electrode)
- positive voltage on outer electrode.

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Diameter of Inner Electrode

14

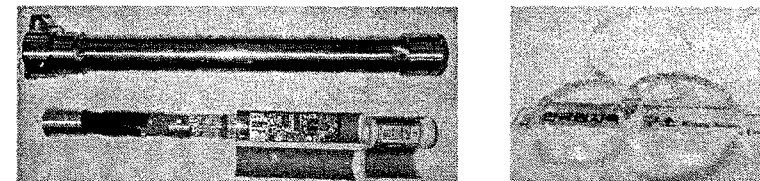


- The collected current is saturated in lower voltage as the diameter of the inner electrode gets bigger.

→ Diameter of Inner Electrode 20 mm

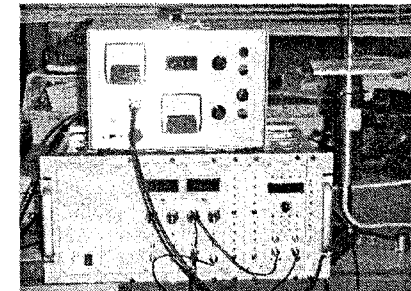
Scintillation Detectors

16



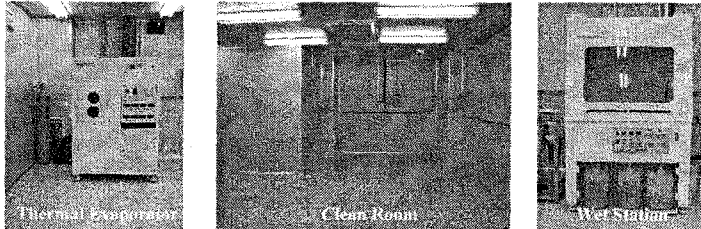
- CsI(Tl) detector for the thickness gauge

- Plastic scintillator for β -ray RMS



Semiconductor Radiation Detectors

- **Clean Room**
 - 47.6m², class 1000
- **Thermal Evaporator**
 - 10⁻⁷ Torr
 - Thickness monitor ~ 0.1nm
 - 4Ea W-boats, 800°C substrate
- **Wet-Station**
- **More equipments for semiconductor detector will be installed.**

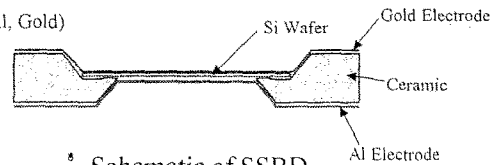


Future Research

- **Room temperature semiconductor detector**
 - Semiconductor detector in radiation environment
 - Radiation hardness
 - High Z, large band gap semiconductor. operation in room temp
 - The choice of GaAs, CdZnTe, CdTe over Si
 - Industrial application and the new RMS(Radiation Monitoring System) Detector
 - Our group is interested in the development of the room temp semiconductor sensor
 - Single crystal growing for the radiation sensor

Study of Silicon Detector

- **SSBD (Silicon Surface Barrier Detector)**
 - MIS (Metal-Insulator-Semiconductor) structure
 - The spectroscopy of charged particle, alpha particle, heavy ion and fission fragment
 - Particle identification
- Silicon Wafer (n-type, (111), 0.5 mm, 2000 kΩ-cm)
- Cutting (diameter of 3 cm)
- Cleaning
- Etching (CP-4A)
- Housing
- Metal Evaporation (Al, Gold)
- Packing



8 Schematic of SSBD

Luminescence of ZnSe(Te) excited by plasma layer of indium tin oxide

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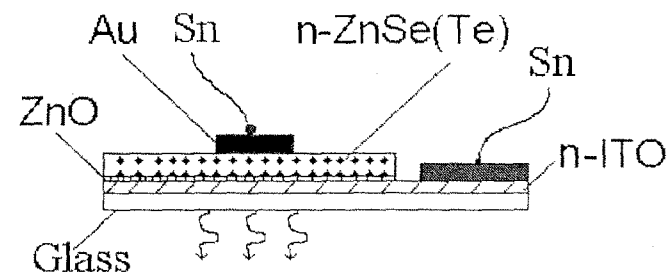


Fig 1 The structure of the samples used in the given work. The wavy lines with arrows indicate the direction of the radiation under the current excitation.

The samples of the structures look like glass plates 2 x 1 sm long and 0.2 sm thick with condensed active layer or pressed crystals

Luminescence of ZnSe(Te) excited by plasma layer of indium tin oxide

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Luminescence of n-ZnSe(Te) can be excited by X-ray impulses – in this case we have scintillator and by electric current – in this case this material is used in the light emitting diode. The problem of stabilization of regime of work of high powerful blue-green diodes and lasers is actual today. Existing now GaAs/ZnSe laser diodes is destroying with time. Semiconductor with smaller forbidden band or metal with high work function usually used in the anodic region extracts the main carriers from the ZnSe. This lowers the electroluminescence efficiency of this structure.

To overcome this effect, we have used a thin monoatomic oxide layer on the n-ZnSe(Te). It is formed on the surface of the freshly cleaved zinc selenide crystal due to chemisorption of oxygen. The ZnSe(Te) crystal with an oxide layer was introduced into contact with a transparent anode made of indium and tin oxides (ITO). Excitation of the samples was made on IBM PC source of voltage. The special program specified a mode of excitation and formed the videomap of tabular given the voltage-current characteristic. It all time sorts the dynamically going data by a method of a floating up bubble by criteria that was assigned to the user. In the given work the data dynamically were sorted on increasing value of argument, i.e. ruling voltage.

The synthesized structure has exhibited properties of a light emitting diode (LED). It has band of radiation in the field of 540,640 and 740 nm. The direct mode region in the energy range of 0-20 eV had N-shaped character. Our calculations have shown that the extremum at about 16 eV can correspond to resonance tunneling of holes through the quantum-dimensional ZnO layer. The thickness of this layer was calculated using the de Broglie wavelength of the carrier. It was found to be close to the lattice period of the oxide layer on the surface of the ZnSe(Te) crystal.

The composition of the received films ZnSe(Te) according to the X-Ray analysis are in the Table 1

Table 1

Substance	Zn,% At	Se,% At
Source ZnSe(Te)	51,632	48,368
Growth film	47,369	52,631

In the limits of measurement's error the table data shows that the composition of the film and sores crystal are similar. The lack of cations was filled by following exposure of crystals in the atmosphere of saturated vapour of Zn under high temperature.

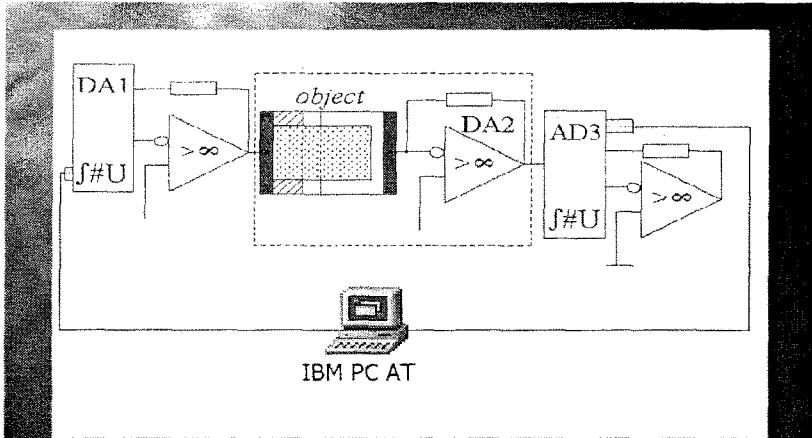


Fig. 2. The structured scheme of the device for reception of the voltage-current features of the electroluminescent hybrid structure.

The program, assigning the mode of the excitation and forming videomaging of the tabulary given voltage-current feature, all time sorts dynamically entering data by method of floating bubble on the criterion, assigned by user.

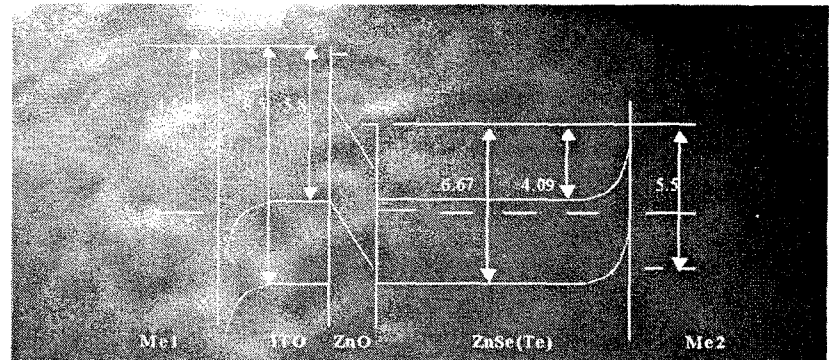


Fig. 4. Zone diagram of hybrid electroluminescent structure Me/n-ITO/ZnO/n-ZnSe(Te)/Me in zero bias. The digits show position of energy levels relatively vacuum in eV.

By zero bias (zero control voltage) there is the contact barrier on the interface ITO-ZnSe(Te), which equalizes chemical potentials of two materials. Physically, it appears because of capture of electrons diffused from ZnSe(Te) at interface boundary.

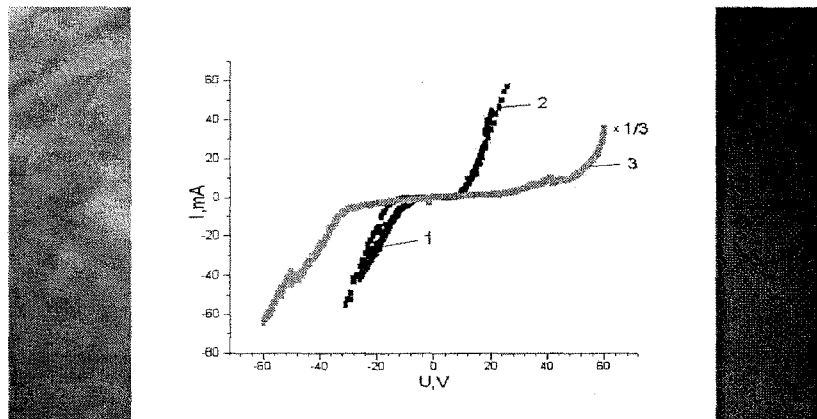


Fig. 3. The dependence of current I from voltage U for ZnSe(Te) crystal with symmetrical contacts, made from 1-Pb(4.0), 2-Sn(4.38), 3-Au(5.2). There is the work function (eV) in brackets.

The form of the dependence having been shown on the fig 3 did not depend on the distance between electrodes and on the sickness of the sample. This means that

voltage used was really concentrated at the thin range near electrodes.

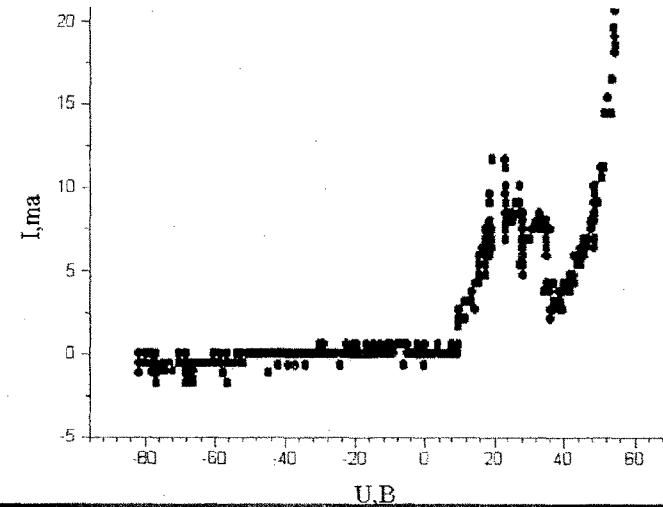


Fig. 5. The voltage-current feature of the n-ZnSe(Te)|ZnO|n-ITO structure. Minus was given on to the injecting electrode in the right corner of the Fig.

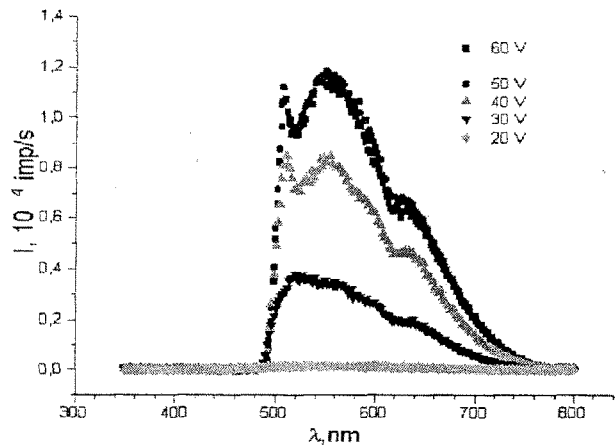


Fig. 6. The spectrum of the radiation of the ZnSe(Te) Zn crystal. The excitation by direct currents under different controlling voltages marked on the figure.

Unlike the spectrum of its luminescence, basic peak of the elektroluminescence is found in the 550 nm region.

Luminescence of ZnSe(Te) excited by plasma layer of indium tin oxide

Conclusion

1. The samples n-ZnSe(Te)|ZnO|n-ITO with the led structure and N - figurative volt-current characteristic are received.
2. Two ways of excitation of luminescence: impacting - direct interaction of the carriers with the centers of the luminescence and recombination - capture by the center of luminescence of the hole and electron and following radioactive recombination were found during the investigation of the electroluminescence in n-ZnSe(Te)|ZnO|n-ITO structure. Injection of the holes results in appearance of the volume's luminescence in ZnSe(Te) crystals.
3. The quantum barrier of ZnO limits the flow of the current carriers in both sides. Moreover, it is possible to control the energy of the carriers and influence the efficiency of the excitation process by means of selection the ZnO layer thickness.

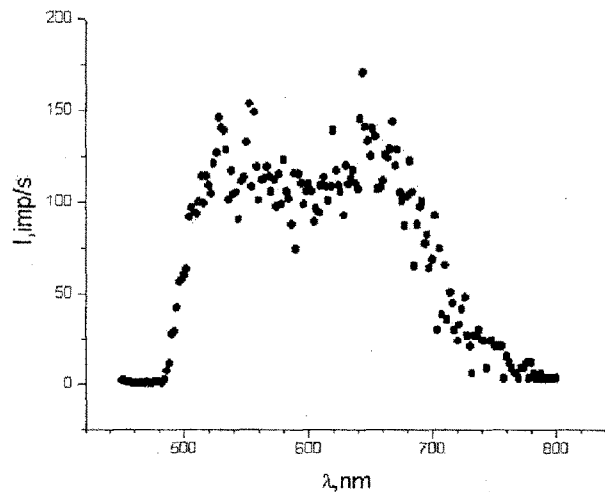


Fig. 7. The spectrum of the radiation of the lightemitting n-ZnSe(Te)|ZnO|n-ITO structure under controlling voltage 60 V. Minus is attached to the injecting in ZnSe(Te) electrode.



STC RI, STC «Institute for Single Crystals», NASU

Recent investigations of complex oxide scintillators

V.Ryzhikov, E.Pirogov, B.Grinyov, L.Nagornaya,
V.Bondar, G.Onyshchenko, B.Tsapenko,
V.Krivoshein, I.Babiychuk, K.Katrunov,
I.Tupitsyna, V.Spasov, S.Galkin, E.Voronkin,
E.Loseva

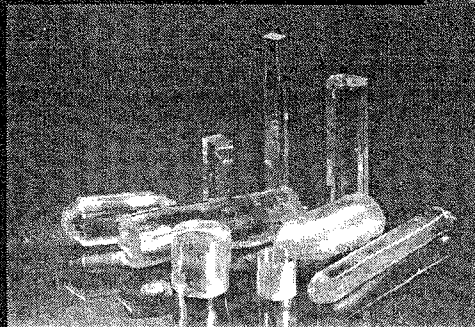
UKRAINE
2003

Extensive studies have been carried out of their optical-luminescent, scintillation (including studies under various irradiation conditions and absolute light yield), thermo-stimulated and mechanical properties. Attention was paid both to effects of various technological parameters on these properties and to fundamental aspects of the nature of luminescence centers, mechanisms of accumulation and transformation of energy in crystals.

Our objective is to expand the possibilities of application of detectors based on these crystals in various fields of modern techniques and radiation monitoring



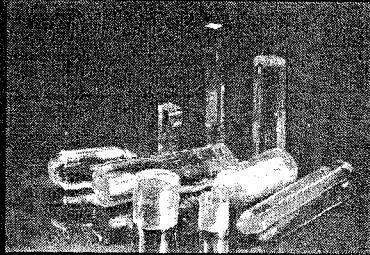
Works on production and studies of complex oxide scintillation single crystals as a field of scientific research were initiated in the Institute for Single Crystals in 1986 on the initiative of Academician V.P.Seminozhenko, who always paid much attention to this scientific direction. Great attention to works on oxide scintillators carried out under international programs was paid also by Corresponding Member of the Academy of Sciences of Ukraine B.V.Grinyov. Scientific and Technological Center for Radiation Instruments (STC RI) of STC «Institute for Single Crystals» has been carrying out development and continuous improvement of the production technology of complex oxide single crystals (CWO, GSO, BGO, PWO) of high quality.



Comparative characteristics of scintillators

Characteristics and properties	CsI(Tl)	BGO	CWO	PWO	GSO
Effective atomic number	54	74	66	73	59
Density, g/cm ³	4.51	7.13	7.9	8.23	6.71
Radiation length, cm	2.2	1.02	1.06	0.85	1.38
Refraction index	1.80	2.15	2.2-2.3	2.2	1.85
Hygroscopicity	slightly	No	No	No	No
Luminescence maximum, nm	550	480	490	430	440
Decay time, ns	1,000	300	5,000	3/10/30	60/600
Light output (662 keV), Photon/MeV	55,000	8,000	15,000	200	9,500
Radiation stability, rad	10 ⁴	10 ⁵	10 ⁷	10 ⁷	10 ⁶
Afterglow after (20) ms, %	0.1-5	0.005	1.05	(<0.01)	

Lead tungstate $PbWO_4$ (PWO)



PROBLEMS:

- Due to presence of residual stresses PWO crystals are difficult for mechanical treatment;
- "Cloudy" region along the growth axis leads to light scottering;
- Microinclusions and color centers (intense yellow, grayish), causing decreases in optical transmission, light output and radiation stability.

Improvement of transmission spectra and light output of PWO after the thermal treatment are presented in the Table.

Scintillator No.	Light output, photoelectrons/MeV		Transmission, %			
	Initial value	After stage-by-stage thermal treatment	$\lambda=360$ nm		$\lambda=420$ nm	
			Initial value	After stage-by-stage thermal treatment	Initial value	After stage-by-stage thermal treatment
1	4,0	10,8	0	16	10	55
2	4,0	7,0	0	10	5	50
3	3,4	7,6	0	10	5	50
4	3	6,4	0	10	10	48

The observed increase in optical transmission can be explained by eliminating of defects of the "cloudy" region, as well as residual post-growth stresses after the first stage and by decomposition of color centers $Pb^{3+} \rightarrow Pb^{2+}$, which leads to higher transparence in the $\lambda=360$ nm band, and $O^- \rightarrow O^{2-}$ - in the $\lambda=420$ nm band after the second stage of thermal treatment (see Fig.1).

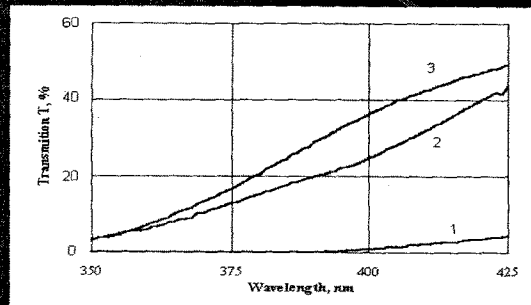


Fig. 1 Transmission spectra of PWO scintillator
1 - initial, 2 - after the first stage, 3 - after the second stage of thermal treatment.

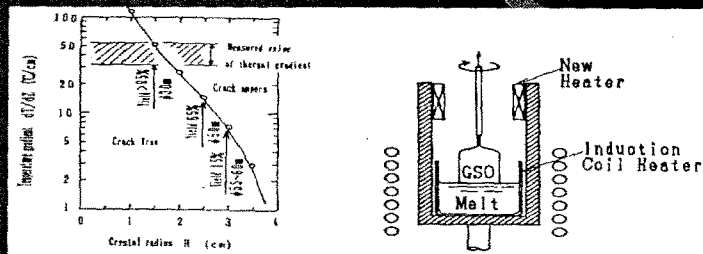
CONCLUSION

Thus, the above-indicated problems of PWO crystals CAN BE SOLVED BY CONSUMING OF stage-by-stage thermal treatment of PWO crystals in a controlled atmosphere.

This, under certain conditions, leads to stage-by-stage removal of defects of different types and improves transparence and scintillation parameters.

INVESTIGATIONS ON GROWTH, THERMAL AND MECHANICAL TREATMENT OF GSO CRYSTALS

Now we improve technology of producing GSO crystals of larger size using new design of crystallization unit

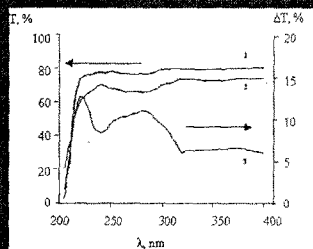


a) Crystal radius versus critical temperature gradient causing cracks;
b) Two-zone furnace

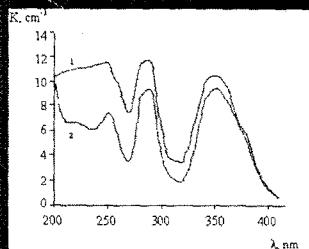
CONCLUSIONS

- The use of two-zone furnace in crystallization unit and improved growing technology allow to produce GSO crystals of large size without cracks;
- The thermal treatment in a controlled atmosphere allows to improve transparence and energy resolution of GSO crystals;
- Investigations of anisotropy of mechanical properties of GSO crystals allow to establish optimal sequence of technological stages of their mechanical treatment.

Effect of thermal treatment in a controlled atmosphere upon transparence and energy resolution of GSO crystals



Transmission spectrum of GSO(Ce) crystal: 1 – after thermal treatment; 2 – before thermal treatment; 3 – difference between the transmission spectra of the annealed and nonannealed samples.



Absorption of GSO(Ce) sample: 1 – before thermal treatment; 2 – after thermal treatment. For GSO(Ce) scintillator dia. 27 mm and 90 mm length with a HAMAMATSU R1307 PMT the energy resolution of 8.5% (^{137}Cs) was obtained.

Scintillation characteristics of CWO crystals with different dopants

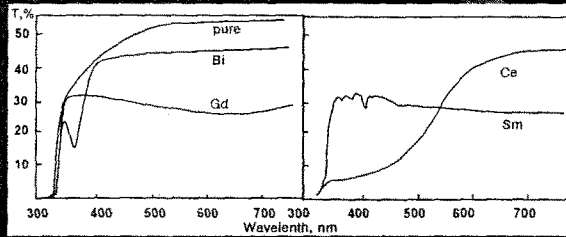
Dopants	pure	Cd	Li	Na	Zn	Pb	Bi	Cr	Fe	Gd	Hf	Zr	Nb	Ta
Concentration, mass. %	-	0.25	0.1	0.01	0.1	0.1	0.025	0.025	0.005	0.05	0.03	0.003	0.01	0.03
Light output, %	100	98	107	99	90	64	50	20	41	49	47	98	8	74
Afterglow (20 ms after excit.), %	0.014	0.013	0.008	0.008	0.026	0.03	1.5	0.018	0.03	0.09	0.033	0.019	0.035	0.02

Analysis of the table data allows us to conclude that introduction of isovalent dopants in most cases does not practically affect the light output and afterglow as compared with the nominally pure crystals.

Univalent dopants decrease the afterglow and increase light output.

At present it is established:

- ° Oxygen vacancies are predominant structural defects in CWO crystals.
- ° After introduction of heterovalent dopants, especially, trivalent (Gd^{3+} , Sm^{3+} , Ho^{3+} , Bi^{3+} , etc.), complex structures are formed, which comprise dopant ions, reduced tungsten (W^{5+}) or an F-center. Therefore, such dopants most strongly affect the above CWO crystal parameters.



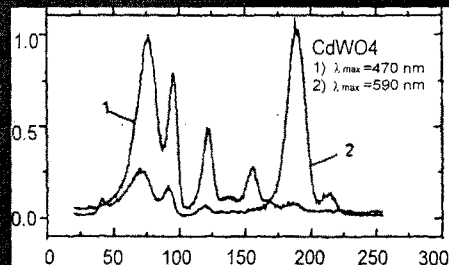
° Transparence decreases in the 500-600 nm range

Analysis of CWO TSL spectra obtained for nominally pure crystals subjected to thermal annealing in different conditions (cadmium vapor, vacuum, oxygen) allowed us to identify the most intense TSL peaks – $T_m=184$ K and 208 K.

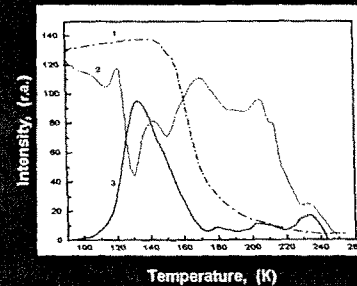
The 184 K peak is due to the capture levels related to defects in the cadmium sublattice, and the $T_m=208$ K peak – to defects in the oxygen sublattice.

THERMOLUMINESCENCE AND OTHER THERMOSTIMULATED PHENOMENA

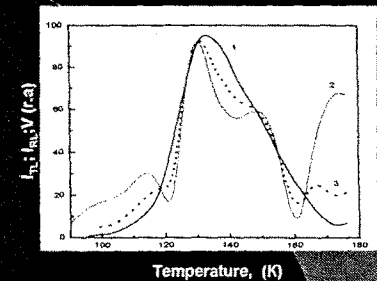
Figure shows the TSL spectrum of a nominally pure CWO crystal. A set of peaks is observed in the 90-280 K range, with their relative intensity and position depending upon the initial degree of defectness of the sample.



TSL spectra of PWO crystals

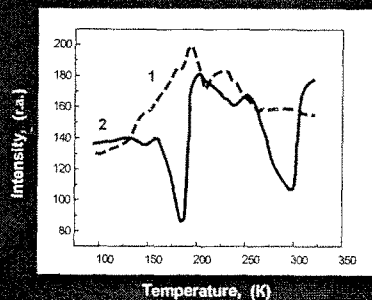


1- temperature dependence of RL of nonirradiated sample; 2- temperature dependence of RL of irradiated sample; 3-TL curve.

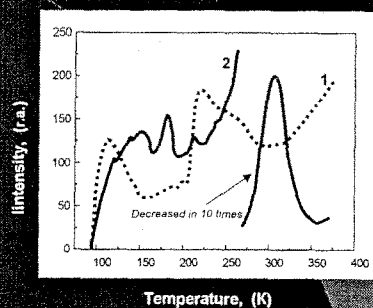


1- TL curve; 2- temperature dependence of ΔI_{RL} ; 3- temperature dependence of release speed.

TSL spectra of GSO crystals



Temperature dependence of PHL: 1 - for nonannealed sample; 2 - for annealed sample.

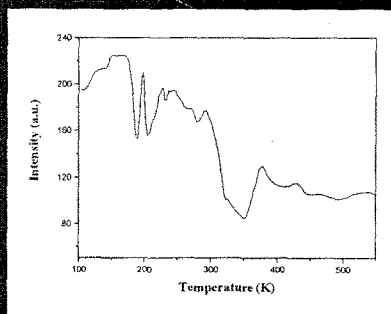


Temperature dependence of photocurrent in annealed sample: 1 - under cooling (nonirradiated sample); 2 - under heating (irradiated sample).

CONCLUSIONS

- The luminescence of complex oxides crystals (CWO; PWO; GSO; BGO) with accumulated light sum has been studied.
- In this case the temperature dependence of luminescence have features it was established.
- They are contained in appearance of minima of intensity in the temperature intervals that correspond to thermal glow.
- This effect has been conditioned on space correlation of the electron traps and the luminescent centers it was established.
- The electron traps and the luminescent centers add up to complex. The accumulation and transformation of excitation energy occurs in such complexes.

TSL spectra of BGO crystals



The temperature dependence of photoluminescence of BGO single crystals ($I_{\text{obs}}=490 \text{ nm}$; $I_{\text{exc}}=285 \text{ nm}$)

Studies of some scintillation properties

- Absolute light yield for some CWO, BGO, GSO crystal samples was measured.
- Scintillation characteristics of bismuth germanate crystals under external and internal radiation was studied.

ABSOLUTE LIGHT YIELD MEASUREMENTS OF OXIDE AND ALKALI HALIDE SCINTILLATORS

Scintillator	Size, mm ³	Photo-electrons / MeV	Technical light yield (Ph/MeV)	Absolute light yield (Ph/MeV)	Light collection coefficient, τ
CsI(Tl)	10x10x10	2695	21385	45543	0.47
-//-	10x10x5	3970	31510	45282	0.70
-//-	10x10x2	5035	39957	45152	0.88
CWO	10x10x10	1668	8561	19840	0.44
-//-	10x10x5	2549	13221	19840	0.67
-//-	10x10x2	2790	14469	19848	0.73
BGO	10x10x10	675	3861	7661	0.50
-//-	10x10x5	785	4490	7662	0.59
-//-	10x10x2	956	5467	7667	0.71
GSO	10x10x10	784	3019	7508	0.40
-//-	10x10x05	1321	5088	7510	0.68
-//-	10x10x02	1399	5388	7508	0.72

The use of GSO and CWO scintillators in X-range radiometers

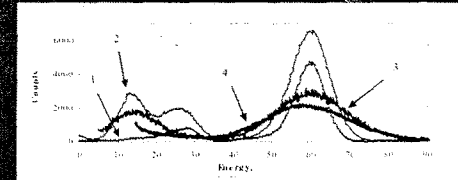
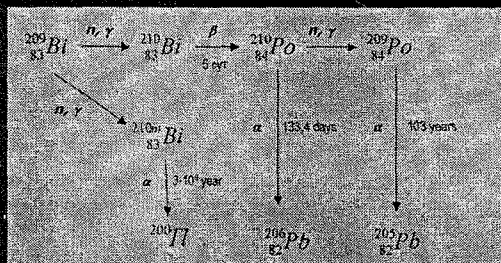


Figure 1: Response of scintillators GSO, BGO and NaI(Tl) upon irradiation by ²⁴¹Am and ¹³⁷Cs.

1- NaI(Tl) dia 25x25 mm²; 2- NaI(Tl) dia 40x2 mm² (energy resolution 15-16% at 59.6 keV); 3- GSO 25x25x2 mm³ (energy resolution 23% at 59.6 keV); 4- BGO dia 25x25x3 mm³ (energy resolution 38% at 59.6 keV).

- 67 -

SCINTILLATION CHARACTERISTICS OF BISMUTH GERMANATE CRYSTALS UNDER EXTERNAL AND INTERNAL RADIATION



Additional sources of the background for detectors based on bismuth germanate crystals was studied. A possibility has been shown for creation of reference scintillators on the basis of bismuth germanate crystals irradiated by thermal neutrons.

The use of GSO and CWO scintillators in X-range radiometers

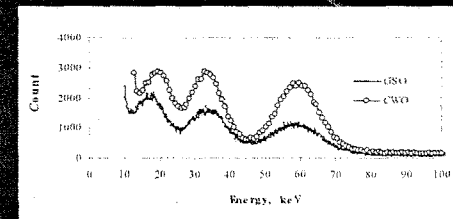


Figure 2: Response of oxide scintillators GSO and CWO upon irradiation by ²⁴¹Am and ¹³⁷Cs. Shaping time constants are equal to 6 μ s.

The use of GSO and CWO scintillators in X-range radiometers

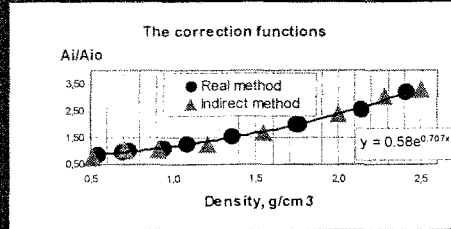
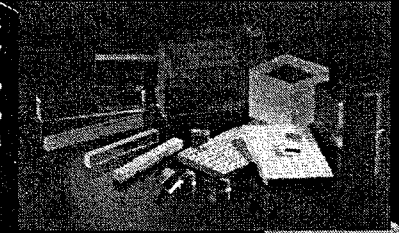


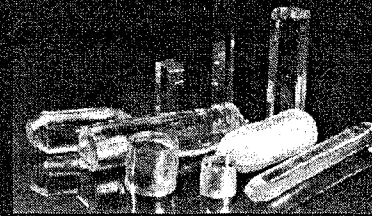
Figure 3: Correcting functions accounting for self-absorption in samples at different densities obtained by two different methods

THE MOST IMPORTANT RESULTS

1. The obtained scientific & technical results have been widely used in production of CWO, BGO, GSO, PWO crystals, scintillators and scintillation arrays and assemblies.



2. They are realized within the framework of international cooperation with Republic of Korea, USA, Germany, Netherlands, Russia, France, Switzerland (CERN) and other countries.



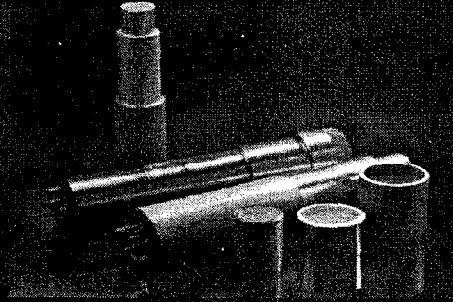
Measurement results for real Chernobyl samples obtained using RK-AG-02 radiometer (GSO scintillator) and Ge(Li) spectrometer.

Sample density	Activity of ^{241}Am (by RK-AG-02M), Bq/kg	Activity of ^{241}Am (by Ge(Li)), Bq/kg	Deviation, %
0.54	433	498	-13.1
0.94	257	310	9.5
1.64	611	690	-8.0
2.2	503	452	-4.3

Characteristics of scintillation complex oxide single crystals developed and produced by STC RI

Type of crystal	Maximum dimensions, mm	Light yield, photoel/MeV	Energy resolution (^{137}Cs , $\varnothing 40 \times 40$ mm), %	Afterglow after 20 ms, %
BGO	$\varnothing 75 \times 150$ $\varnothing 55 \times 230$	7700-8000	10.5-13	0.005
CWO	$\varnothing 60 \times 150$	20000	7-8	0.015
GSO	$\varnothing 55 \times 180$	7500-8500	9-11 28...30 (60 keV)	-
PWO	$22 \times 22 \times 180$ $22 \times 22 \times 200$	200	<0.3% for E = 50 GeV	-

THE MOST IMPORTANT RESULTS



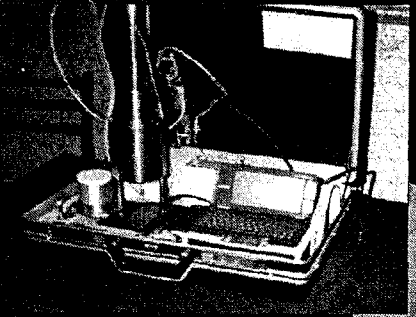
Scintillation detection blocks on the basis of BGO, CWO, GSO crystals

3. On the basis of BGO, CWO, GSO single crystals highly efficient scintillation detection blocks have been created.

THE MOST IMPORTANT RESULTS

4. A small-sized portable alpha-gamma radiometer has been developed on the basis of GSO, designed for measurements of specific activity of ^{241}Am under conditions of strong background radiation of other radionuclides.

Detection blocks and radiometer are now in experimental operation at the Chernobyl exclusion zone.



Selective alpha-gamma radiometer RK-AG-02

Technical characteristics of scintillation detection blocks

Parameters	Radionuclide	BGO 40 x 40 mm	CWO 40 x 40 mm	NaI(Tl) 40 x 40 mm
Amplitude resolution, %	Cs-137	13.5-12	8-10	9.0-10.5
Resolution, %	Cs-137	15	12	8
Energy resolution, %	Cs-137	5.6	5.2	3.4
Energy resolution, %	K-40	2.36	2.0	-
Energy resolution, %	Cs-137	0.15	0.57	0.34
Energy resolution, %	Cs-137	0.22	0.26	-
Energy resolution, %	Cs-137	0.38	0.36	2.0-2.2
Energy resolution, %	Cs-137	0.5	0.5	-
Energy resolution, %	Cs-137	1.4	1.5	13.7
Energy resolution, %	Cs-137	1.5-2.0	1.5-2.0	1.5-2.0
Energy resolution, %	Cs-137	1.5	1.5	1.4

Technical characteristics of alpha-gamma radiometer RK-AG-02

Measurement range of specific activity during 6-7 min, Bq/kg	30 - 10,000
Maximum activity of accompanying radionuclides, Bq/kg	1,000
Exposure time, min	1 - 40
Consumed power, W	15
Voltage, V	220 or 12
Overall dimensions, mm	
Detection block with passive protection	100 x 365
Data processing block	245 x 200 x 75
Mass of the instrument, kg (5 kg passive protection)	13

THE MOST IMPORTANT RESULTS

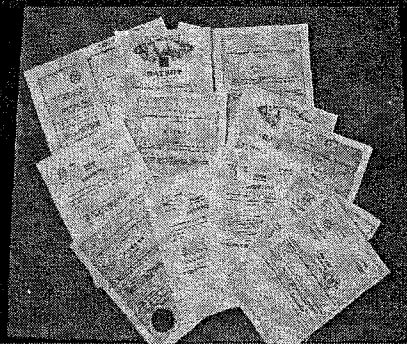
These instruments are a part of the complex of nuclear physics instruments, the development of which was distinguished by the State Award of Ukraine in the field of science and technology in 2000.

THE MOST IMPORTANT RESULTS



- At the 30th International Inventions Exhibition (Geneva, Switzerland, 2002), achievements of STC RI were marked by Diploma and Golden Medal.

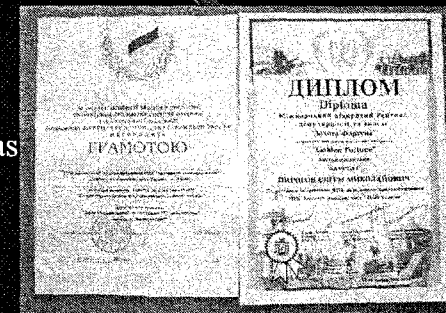
THE MOST IMPORTANT RESULTS



More than 40 patents have been obtained for our developments on complex oxide scintillation crystals and instruments on their base.

THE MOST IMPORTANT RESULTS

- In 2001 STC RI has obtained an award at the All-Ukrainian Inventions Competition, as well as Diploma of the International Open Popularity & Quality Rating "Golden Fortune".



THE MOST IMPORTANT RESULTS

**Recent publications and patents
(1997-2003)**

- **Monograph (V. Ryzhikov, B. Grinyov et al.) - 1**
- **Articles in well-known scientific journals – 45**
- **Reports on International conferences – 55**
- **Patents – 17.**

THERMOTROPIC LIQUID CRYSTALLINE SYSTEMS IN BIOEQUIVALENT DOSIMETRY

L.N. Lisetski, V.D. Panikarskaya, N.A. Kireyeva,
O.Ts. Sidletskiy

*Institute for Single Crystals, 60, Lenin pr., 61001 Kharkiv,
Ukraine;*

e-mail: lisetski@isc.kharkov.com

Natural cell membranes:

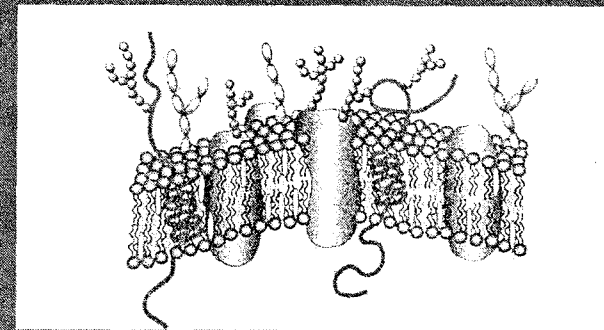
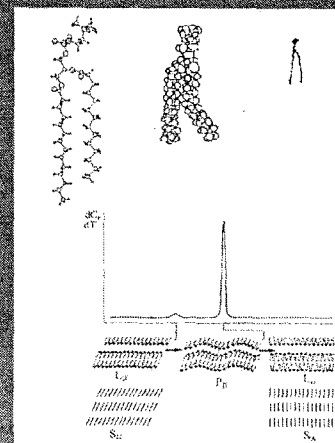


Fig.1. Schematic drawing of a biological membrane

The levels of biological structures modeling:

- natural cell membranes;
- artificial "natural" membranes;
- multilamellar structures of hydrated phospholipids (a commonly accepted structure for model membranes);
- thermotropic liquid crystalline systems.

Multilamellar structures of hydrated phospholipids (a commonly accepted structure for model membranes),



- Fig.2. Phase transitions gel – liquid crystal in hydrated phosphatidylcholines and correspondence between thermotropic and lyotropic mesophases

Thermotropic liquid crystalline systems

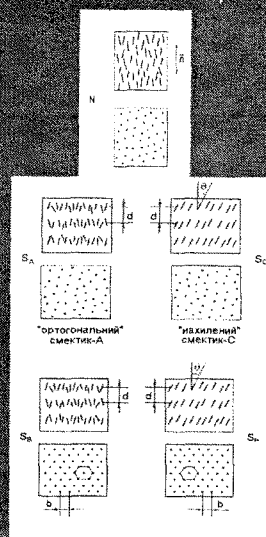
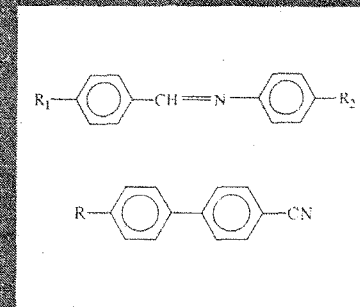


Fig.3. Supramolecular structure of different types of mesophases

Bioequivalent systems

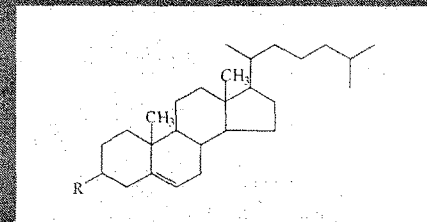
- (1) liquid crystalline mixture of Schiff bases, namely eutectic mixture of 4-methoxy-benzylidene-4-butylaniline (MBBA) and its alkoxy homologue
 $R_1 = -OCH_3$ $R_2 = -C_4H_9$ — MBBA
 $R_1 = -OC_2H_5$ $R_2 = -C_4H_9$ — EBBA
- for which reversible changes of molecular configuration (trans-cis-transitions) had been observed under small doses of ionizing radiation
- (2) eutectic mixture of liquid crystalline 4-alkyl- and 4-alkoxy-4'-cyano-biphenyls, which was used as a standard reference liquid crystalline system
- (3) non-saturated long-chain carboxylic acids (namely, oleic), which is a substance of biological origin and for which some features of liquid crystalline ordering and radiation-stimulated response were observed under certain conditions.



In this case, two aspects are taken into account:

- similarity in supramolecular ordering (orientational and translational), e.g. L-alpha and L-beta phases of hydrated phospholipids are considered similar to smectic-A and smectic-H phases, respectively.
- similarity in molecular structure. Very promising are thermotropic liquid crystals formed by cholesterol esters (one should remember that cholesterol and other steroids are formally lipids and are an important constituent part of cell membranes)

Materials



(R: CO_2-CH_2) $_7$ CH=CH(CH $_2$) $_7$ CH $_3$ - cholesteryl nonanoate)

- Cholesteric matrices chosen were based on a mixture of several cholesterol 3 β -derivatives (including cholesteryl nonanoate, cholesteryl formate) and a nematic mixture of 4-butyl- and 4-hexylcyclohexanecarboxylic acids (4CHCA+6CHCA, 1:1).
- The mass fraction of the nematic constituent was 40% (Matrix 7) or 60% (Matrix 8).
- The dopants used included ergosterol (provitamin D2) and ergocaliferol (vitamin D2) which were incorporated into the cholesteric matrices in quantities of 1-5 mass. %

The aim of the work

To check a possibility of a new sensor materials creation based on CLC for monitoring of the biologically active fraction of UV radiation. The idea comprises an introduction of natural "precursor" of vitamin D (e.g. provitamin D2 or D3) into an appropriate cholesteric matrix. Formation of vitamin D under UV irradiation is accompanied by a detectable change in the helical pitch values.

Fig. 6. General scheme of provitamin D photoisomerization.

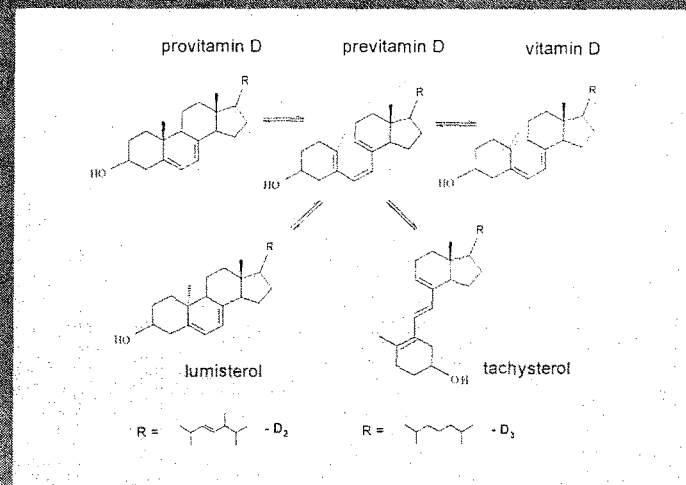


Fig. 4. Structure of cholesteric liquid crystals

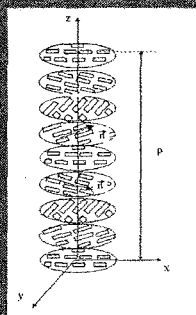


Fig. 5. Change of selective reflection of the matrix 4 with provitamin D2 under UV-irradiation (37 °C): 1 - without irradiation; 2 - 10 min; 3 - 30 min; 4 - 50 min; 5 - 80 min of irradiation; 6 - in a 960 min after the irradiation.

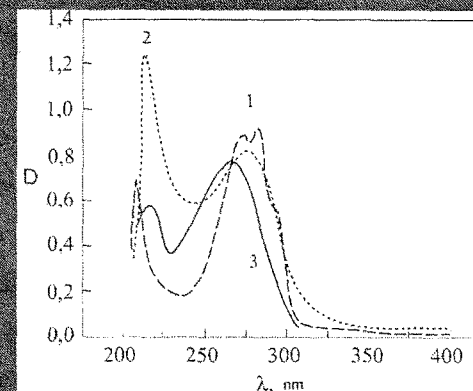
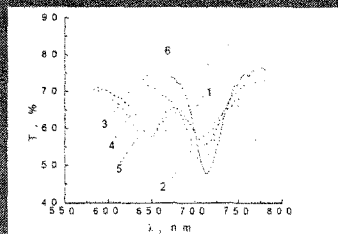


Fig. 7. Absorption spectra (34 °C): 1 - provitamin D2; 2 - provitamin-D2 after 80 min of irradiation; 3 - vitamin D2.

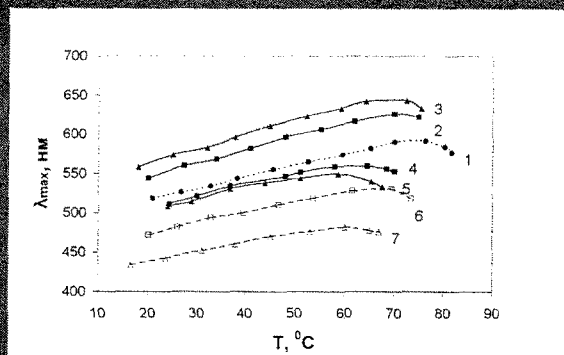


Fig. 8. Maximum reflection wavelength as function of temperature for Matrix 8 with dopants: 1 - undoped Matrix 8, 2 - 3% ProD2, 3 - 5% ProD2, 4 - 3% ProD2, after 30 min irradiation, 5 - 5% ProD2, after 30 min irradiation, 6 - 3% D2, 7 - 5% D2.

The requirements to the holesteric matrix used are the following:

- Matrix transparency in the appropriate UV-region and UV stability. (Matrix compositions used in the present study possesses >50 % transmission down to 250 nm.)
- Stability and wide temperature range of cholesteric phase existence. (Our matrices are sufficiently stable at room temperatures - no crystallization of high-melting components upon cooling them down to 0 °C was observed for at least 10 days.)
- Good solubility of the dopants in the cholesteric matrix.
- SR peak of matrix should be located in the central region of the visible spectrum, making the eventual UV-induced λ_{max} shifts easily remarkable.

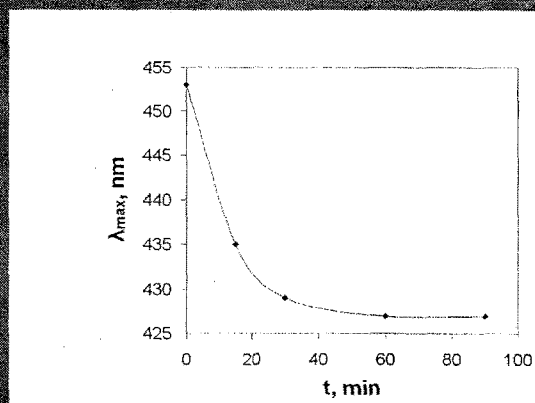


Fig. 9. Maximum reflection wavelength as function of UV irradiation time for Matrix 7 doped with 3% ergosterol (T=37 °C)

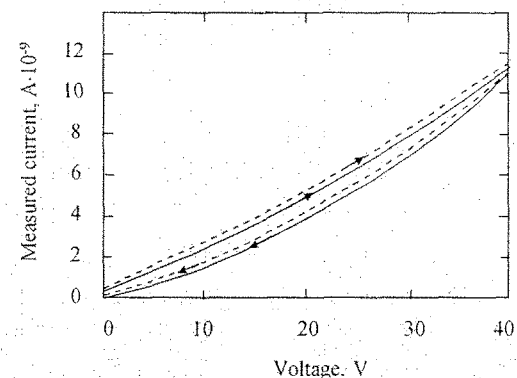


Fig. 10. Voltage-current characteristics for MBBA-EBBA mixture at 20 °C with (dashed line) and without (solid line) irradiation by UV lamp.

CONCLUSIONS

- It has been shown that the method of selective reflection is sensitive enough to be used in studies of UV-induced transformations of vitamin D-related steroids.
- A cholesteric matrix has been developed, which combines reasonable sensitivity of the selective reflection spectra to the steroid dopants, good transparency in the relevant UV-region and thermal stability in a wide temperature range.
- Changes in selective reflection spectra of cholesteric matrices doped with ergosterol (provitamin D₂) under UV irradiation were found to be reproducibly and reliably recordable under commonly used irradiation and measurement conditions.
- Developed matrix can be used as a sensor material for qualitative assessment of the absorbed UV dose rate. Further improvement can be obtained by optimization of the matrix composition and recording conditions.

CONCLUSIONS

- Small but clearly distinct increase of the measured current values was observed under irradiation of MBBA+EBBA mixture by UV light. The observed behavior was generally similar with the other two substances studied, with the effects observed being less marked with oleic acid and practically absent for the cyanobiphenyl mixture.
- Among physical properties sensitive to irradiation of a material the most promising (and used in our laboratory) are phase transitions (thermograms studied by differential scanning calorimetry), temperature-dependent optical transmission spectra (in UV-region – modified by molecular absorption and phase state-induced scattering), and electrophysical properties, i.e. dielectrometry (ϵ and $\tan\delta$) and conductivity as function of temperature and concentration for model systems of different qualitative and quantitative composition.

PROPERTIES UNIFORMITY STUDIES FOR SCINTILLATION ELEMENTS OF 1D- AND 2D-MATRICES ON THE BASIS OF CRYSTALS ZnSe(Te), CdWO₄, CsI(Tl).

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Introduction

In many fields of medicine, visualization methods of internal structures of humans based on tomographic studies are used more and more extensively. These methods of computer graphics are known as volume visualization.

Recently, substantial interest has been noted in methods of image construction using γ - and X-rays. These methods can be used in medical and technical introscopy, in customs and security inspection systems, as well as in systems for γ -image construction.

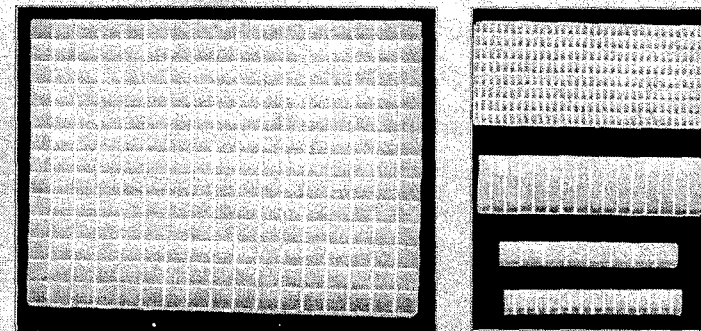
At present, several types are known of multi-element scintillation matrices and detectors on their base. There are shown several types of scintillation matrices in the form of mosaics made of scintillation crystals. To decrease the probability for light from one luminescent flash coming from one scintillation cell to another, as well as to increase emission efficiency of each element, an adhesive-reflecting material is introduced into the inter-element space. However, in the case of Compton scattering, in order to prevent the electron transition from one cell to another, the inter-element space is commonly filled with metal components, e.g., Wood's alloy.

Abstract

Results are presented on parameters of light output and uniformity of scintillation properties of 1D and 2D-matrices for different conditions of their preparation. It has been shown that with grinded scintillators based on ZnSe(Te) and CdWO₄ light output is higher as compared with the polished ones.

Energy resolution and light output has been measured for 2D-scintillators on the basis of CdWO₄, CsI(Tl), ZnSe(Te) for γ -radiation and α -particles from ²³⁵Pu. Advantages of 2D-scintillators over monolithic scintillators are shown.

General view of 1D and 2D scintillation matrices



Experimental

Linear or 1D matrices (arrays) of scintillation crystals are used in scanning X-ray introsopic systems for security & customs inspection, technical detectoscopy, medical computer tomographs. Design and size of the arrays are determined by parameters of the scintillation crystal, effective energy of the radiation source, required spatial resolution values of the introsopic system.

Main characteristics of scintillators that are commonly used for these purposes are given in Table.

From the data presented, it follows that the most suitable for fast introsopic systems are BGO, CdWO₄, ZnSe(Te) and plastics. Accounting for light output, the best among them are ZnSe(Te) и CdWO₄.

As the use of Cd-containing materials is forbidden in EC countries, the most widely used material is CsI(Tl), because its light output is rather high, and its production and applications are technologically well developed.

At present, there is a tendency towards creation of equipment that could function on the real time scale, ensure obtaining of quasi-3D-dimensional images and detection of substances with specified atomic mass of the components. In this aspect, we assume that the most promising for future applications in multi-element detector systems are ZnSe(Te) – for low energies, CsI(Tl) – medium energies, CdWO₄ – high energies.

In this work, we have studied 1D and 2D scintillation matrices made of crystals CsI(Tl), CdWO₄ и ZnSe(Te).

With the aim of studying the effects of scintillator surface treatment quality, uniformity parameters, channel interference under X-ray irradiation, γ -detecting properties, we have prepared samples of multi-element 1D- and 2D-arrays. The fabrication procedure involved cutting of monolithic crystal pieces of ZnSe(Te), CsI(Tl) и CdWO₄.

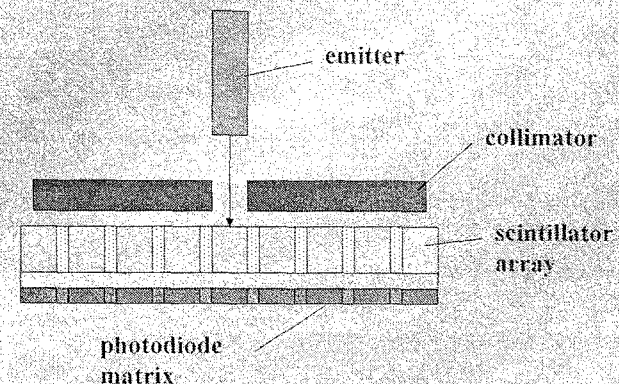
It has been shown that for ZnSe(Te) and CdWO₄, it is preferable to have all surfaces grinded. The signal value increase could reach 15-20%. This can be explained by substantial difference of refraction coefficients between the scintillator and the optical adhesive connection to the photoreceiver.

Channel interference under X-ray excitation was studied using an installation as shown in the block diagram.

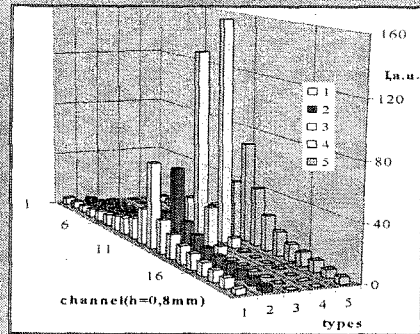
Properties of scintillators used in introsopic systems

Scintillator	Density, g/cm ³	Maximum emission wavelength, nm	Light yield, photons/MeV	Refractive index	Decay constant, ns	Afterglow, %/3ms
CdWO ₄	8.00	480	15000	2.25	1,1	0.05
BGO	7.13	480	9000	2.15	0,3	0.05
CsI(Tl)	4.51	560	59000	1.84	1,0	5
NaI(Tl)	3.67	415	38000	1.85	0,23	5
ZnSe(Te)	5.42	640	45000	2.58	10	0.05
Plastics	1.03	420	≈10000	1.58	0,02	0.05

Block diagram of the installation used for channel interference measurements.



Mutual interference of neighboring channels for different scintillators and types of scintillation elements



1. single crystal plate ZnSe(Te) with $h=0,8$ mm;
2. single crystal plate ZnSe(Te) with $h=0,6$ mm;
3. composite small-crystalline plate ZnSe(Te) (grain size 0,4 nm);
4. individual single elements for each channel;
5. single crystal plate CsI(Tl) with $h=0.8$ mm.

Conclusions

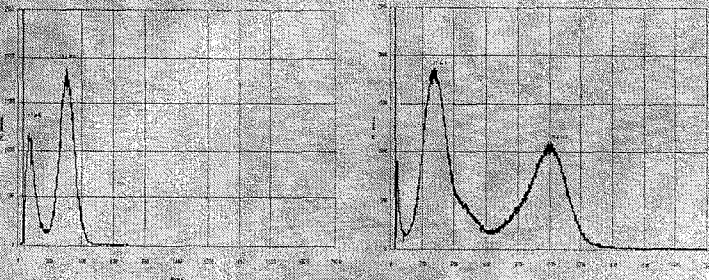
As a result of theoretical calculations and experimental studies of multi-element scintillators, it has been established that:

1. to exclude channel interference above 10 % ,the gap between channels filled with reflecting-adhesive composition (TiO_2 +MgO+ epoxy adhesive) should be at least 0.25 mm thick.
2. for ZnSe(Te) and $CdWO_4$, it is preferable to have all surfaces grinded. The signal value increase is 15-20 %.
3. 2-D arrays fabricated from a monolithic piece ensure high signal uniformity over each channel and can be used in position-sensitive detectors, as well as in spectrometric detectors.

Pulse amplitude distribution spectrum

for a mosaic detector of dimensions $26.5 \times 18.5 \times 2.5$ mm, composed of 105 tomographic elements based on CWO of dimensions $2.5 \times 1.5 \times 1.5$ mm, produced by STC RI, under gamma-excitation from ^{241}Am , $E=69.6$ keV, $R = 33.8\%$, $t=4$ μs , $k=1$, with immersion $C=30.6$ with respect to CsI(Tl).

for a mosaic detector of dimensions $56 \times 42 \times 6.5$ mm, composed of 221 tomographic elements based on CsI(Tl) of dimensions $3 \times 3 \times 5$ mm, produced by STC RI, under gamma-excitation from ^{241}Am , $E=69.6$ keV, $E=17.6$ keV, $R = 63.1 \%$, $t=4$ μs , $k=1$, with immersion.



On the choice of scintillators for “scintillator-photodiode” detectors for digital radiography

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Introduction

Choosing the best scintillator for each specific case is one of the main problems to be solved in the development of instruments and equipment based on scintillation detectors. In principle, the ideal scintillator should possess the following properties: high density, high atomic number, high scintillation efficiency, short emission decay time, low afterglow, good spectral matching with a photoreceiver, and low price. However, such “ideal” scintillators do not exist, and in each specific case a compromise should be looked for, choosing the best suitable material among the available scintillators. In using the linear matrix for detectors and the radiation source, the relevant characteristics can be listed in the following order according to their relative importance:

- Low afterglow – less than 1% after 3 ms;
- High chemical, temperature and radiation stability;
- High density (> 6 g/cm³);
- Luminescence range 500-1000 nm;
- High scintillation efficiency >15 000 ph/MeV.

The theory

As the principal characteristics of a radiographic system are sensitivity (detecting ability) and spatial resolution, we propose the following expression for relative sensitivity as criterion for efficiency of the scintillator used:

$$\left(\frac{\delta}{d}\right)_r \approx \frac{1}{\left(1 - \sum_{i=1}^n A_i \cdot e^{-\tau \cdot (Q_i + \tau)}\right)} \times \frac{\Delta S}{S} \times \frac{\int_0^{E_{max}} \alpha(E) \cdot e^{-\mu_{eq}(E) \cdot d_{eq}} \cdot B(E) dE}{\int_0^{E_{max}} \alpha(E) \cdot e^{-\mu_{eq}(E) \cdot d_{eq}} \cdot d \cdot \mu(E) dE} \quad (1)$$

where: A_i is the contribution of the i -th component of the scintillator X-ray luminescence, δ is diameter of the wire, cm, Q_i are exponential components of the scintillator X-ray luminescence, s , τ is the time constant of the amplifying circuit, s, d_{eq} is the object thickness, cm, V is the object movement speed, cm/s, $\alpha(E)$ is the dose contribution of a specified energy in the X-ray radiation spectrum, $\mu_{eq}(E)$, $\mu(E)$ are linear attenuation coefficients of the object and background object, $B(E)$ is absorption factor of the scattered radiation from the object, $\Delta S/S$ is the threshold contrast of the system (signal to noise ratio for the detector with the amplifying circuit).

The first part describes the amplitude-time characteristic of the system

The second part is described by amplitude-noise characteristics

The third part describes properties of the inspected object.

$$\left(\frac{\delta}{d}\right)_r \approx \frac{1}{\left(1 - \sum_{i=1}^n A_i \cdot e^{-\tau \cdot (Q_i + \tau)}\right)} \times \frac{\Delta S}{S} \times \frac{\int_0^{E_{max}} \alpha(E) e^{-\mu_{eq}(E) \cdot d_{eq}} B(E) dE}{\int_0^{E_{max}} \alpha(E) e^{-\mu_{eq}(E) \cdot d_{eq}} d \cdot \mu(E) dE}$$

$$\frac{\Delta S}{S} \sim \frac{N_{noiseS-PH}}{S_{S-PH}} = \frac{\sqrt{\int_0^{E_{max}} C(E)^2 \cdot n(E) dE}}{\sqrt{q_{sc} \cdot q_{PH} \int_0^{E_{max}} C(E) \cdot n(E) dE}}$$

$$C(E) = (1 - e^{-\mu_{sc} \cdot d_{sc}}) \cdot \frac{Y_{sc}}{\mu_{sc}} \cdot R_{light} \cdot K_{sc}$$

Where q_{sc} , q_{PH} are quantum efficient of the scintillator end the photodiode; μ_{sc} is the linear attenuation coefficient of the scintillator, cm⁻¹; y_{sc} is linear coefficients of electronic conversion of the scintillator, cm⁻¹; d_{sc} is the scintillator thickness; R_{light} is the light collection coefficient in the scintillator to the photodiode, K_{sc} is the spectral matching coefficient of the scintillator luminescence spectrum and the photodiode sensitivity.

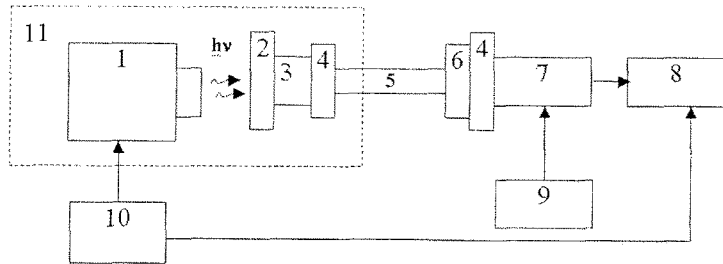


Fig.1. Testing board for measurement of decay time:
 1-pulse X-ray source Mira-2D; 2- X-ray filter; 3- scintillator;
 4- optical collimator; 5-fiber optics light transducer;
 6- optical attenuator; 7- PMT; 8- oscilloscope; 9- PMT power supply;
 10- X-ray source control block; 11- protection chamber.

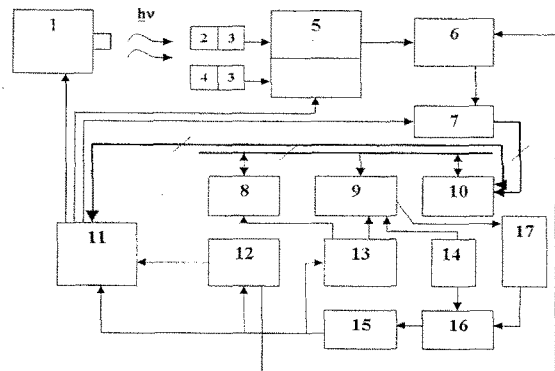


Fig.2. Testing board for measurement of afterglow: 1- X-ray source with controlled grid; 2- tested scintillator; 3- photodiode; 4- reference scintillator; 5- preamplifiers; 6- commutator; 7- 15-digit ADC; 8- memory buffer; 9- transmitter; 10- multiplexer; 11- state register; 12- decreasing step generator; 13- memory buffer controlling device; 14- generator; 15- command decoder; 16- receiver; 17- PC.

Experimental data arrays g_p are approximated by an exponentially decreasing function of the form

$$f(t) = a_1 \exp(-t/Q_1) + a_2 \exp(-t/Q_2) + \dots + a_n \exp(-t/Q_n) \quad (3)$$

Approximation parameters a_i and Q_i are determined by the least squares method, i.e., by minimization of the functional

$$\Phi = \sum [f(t_i) - g_i]^2 \quad (4)$$

The system of normal levels obtained by minimization of Φ is non-linear and can be solved numerically by iterations.

Joining the solution segments together was carried out under conditions of monotonous and continuous amplitude-time characteristic of the scintillator. The respective expressions for these scintillators can be written down as:

for ZnSe(Te)-fast

$$I(t) = 63,1 \exp(-t/3,18) + 31,1 \exp(-t/19,61) + 3,59 \exp(-t/106) + 2 \exp(-t/500) + 0,2 \exp(-t/4100) + 0,01 \exp(-t/795000)$$

for ZnSe(Te)- slow

$$I(t) = 94,9 \exp(-t/10,2) + 3 \exp(-t/19) + 0,03 \exp(-t/87860) + 2,07 \exp(-t/2800)$$

for CsI(Tl)

$$I(t) = 91,91 \exp(-t/0,96) + 4,7 \exp(-t/794) + 2,7 \exp(-t/5731) + 0,41 \exp(-t/43153) + 0,28 \exp(-t/1016711)$$

for CdWO₄

$$I(t) = 49,868 \exp(-t/1,9) + 49,868 \exp(-t/16,5) + 0,25 \exp(-t/2546) + 0,014 \exp(-t/629184)$$

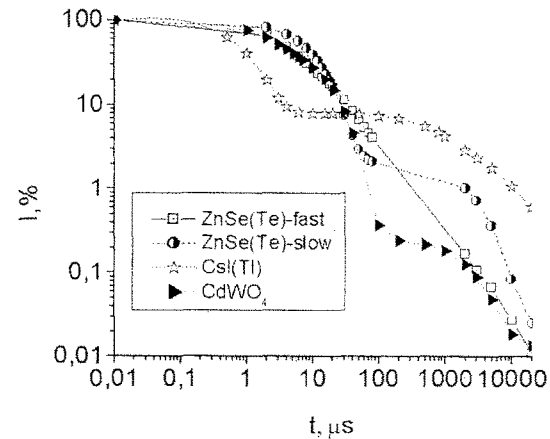


Fig.3. Amplitude-time characteristics of scintillators

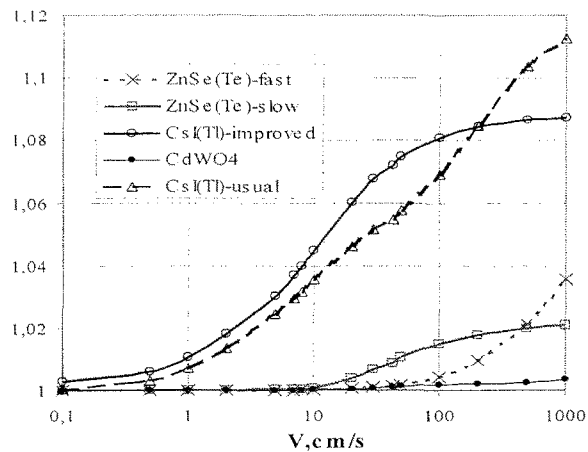
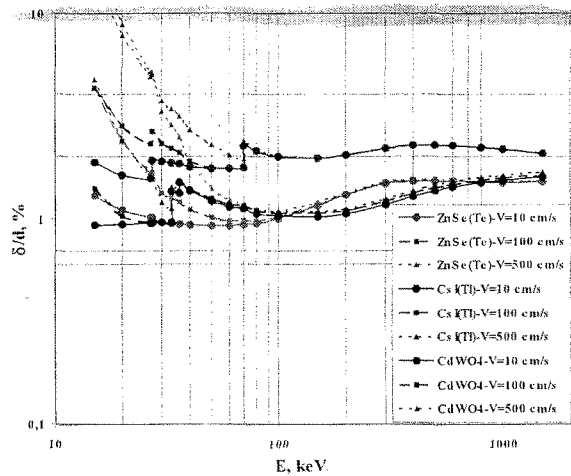


Fig.4. Dependence of relative sensitivity on speed of moving the object at initial sensitivity of 1 % and thickness of a delay of phantom 0.01 cm for SC.

Conclusions

- ✦ In this work, a method has been proposed for efficiency evaluation of scintillators used in "scintillator-photodiode" type detectors for digital radiography. The method is based on expressing the relative sensitivity as function of scintillator characteristics.
- ✦ Mathematical expressions have been obtained for amplitude-time characteristics of scintillators CsI(Tl), ZnSe(Te), CdWO₄, which can be used in designing radiographic systems. Basing on these data, it is proposed that
- ✦ ZnSe(Te) should be used in the 20-100 keV range at object movement speeds up to 100 cm/s,
- ✦ CsI(Tl) – 90-500 keV, up to 100 cm/s,
- ✦ CdWO₄ - > 150 keV at speeds up to 500 cm/s.

Fig. 5. Relative sensitivity of the detecting system using ZnSe(Te), CsI(Tl), CdWO₄ -based detectors as function of radiation energy at different speed of the object movement .



주 의

1. 이 보고서는 과학기술부에서 시행한 원자력연구개발사업의 연구보고서입니다.
2. 이 보고서 내용을 발표할 때에는 반드시 과학기술부에서 시행한 원자력연구개발사업의 연구결과임을 밝혀야 합니다.
3. 국가과학기술 기밀유지에 필요한내용은 대외적으로 발표 또는 공개 하여서는 안 됩니다