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■ 논 문 ■

Intercomparison of the KAERI Reference Photon and Beta Radiation Measurements

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Abstract - This paper describes the results of intercomparison measurements of KAERI reference photon and beta radiation fields between the KAERI and the PNNL(Pacific Northwest National Laboratory), recently performed at KAERI radiation calibration and dosimetry laboratory on the basis of the ANSI N13.11 criteria for personal dosimeter performance test. Each laboratory used her own radiation detectors or measurement devices traceable to her national primary standard in measuring the exposure rates for photon fields, the absorbed dose rates for beta radiation fields. The agreements in reference radiation measurements between two laboratories were found to be less than ± 2.0 % for photon fields, ± 1.0 % for beta radiation fields. Therefore, it could be concluded that KAERI reference radiation fields comply well with the international standard and thus can further serve as a national basis for the researches and developments in radiation protection dosimetry in Korea.

Key words : reference radiation(fields), calibration, traceability, exposure, air kerma, ANSI, ISO

요약 - 이 논문은 최근 한국원자력연구소(KAERI)와 미국 패시픽노스웨스트 국립연구소(일명, 바텔연구소, PNNL)이 개인선량계의 성능검사를 위한 미국 ANSI N13.11 기준에 근거하여 KAERI 방사선 측정/교정실험실에서 수행한 KAERI 기준 광자 및 베타 방사선장의 국제 상호비교 측정결과를 설명하고 있다. 두 기관이 각각 자국의 일차 표준에 소급성을 갖는 방사선 검출기와 방사선 측정장치를 사용하여 자유공기중에서 광자의 조사선량(율), 공기커마(율)와 베타선의 절대흡수선량(율)을 측정한 결과, 광자선장에 대해서는 ± 2.0 %, 베타선장에 대해서는 ± 1.0 %의 오차범위내에서 잘 일치하였다. 따라서 KAERI의 기준 광자 및 베타 방사선장은 국제표준에 잘 만족되고 있음이 입증되었으며 장차 방사선 도시메트리 연구개발의 국가 기술기반으로 활용될 수 있음이 확인되었다.

중심단어 : 기준방사선(장), 교정, 표준소급성, 조사선량, 공기커마, ANSI, ISO

INTRODUCTION

Radiation measuring instruments and personal dosimeters used for the radiation protection purpose should be periodically calibrated to maintain the reliability and precision of the measured results. For this reason, establishment of proper reference radiation fields and national secondary calibration laboratory are very important for the radiation protection dosimetry. General requirements for a secondary calibration laboratory are well described in the International Organization for Standardization(ISO) Guide 25.[1]

The national primary calibration laboratory which maintains a national calibration standard and traceability system normally provides calibration of instruments used at the secondary calibration laboratory. The calibration interactions between the primary and the secondary laboratory are usually formalized by means of an accreditation program or by specific measurement quality assurance programme to maintain a national calibration standard traceability system.

The degree of consistency required for calibration in a secondary calibration laboratory is generally accepted to be within about ± 3 %, and the overall uncertainty in calibration measurements is usually maintained to be within about ± 5 %[1,2].

Since 1978, Korea Atomic Energy Research Institute(KAERI), one of the national secondary calibration laboratories in Korea for the radiation measurement has provided calibration services of various radiation measuring instruments and irradiation of personal dosimeters for the performance testing, and currently performs studies on radiation protection dosimetry.

This paper describes the KAERI reference radiation fields established by recent mid and long term project of nuclear energy development and shows the results of international intercomparison measurements between KAERI and PNNL(Pacific Northwest National Laboratory), which is an U.S. secondary calibration laboratory that serves as a proficiency testing laboratory for the U.S. National Voluntary Laboratory Accreditation Programme(NVLAP) of personal dosimeters performance test[3] to investigate and confirm the degree of consistency of reference radiation fields and beam qualities being independently maintained by each calibration laboratory.

EXPERIMENTAL METHODS

The methods used for measurements of the exposure rate of photon and the absorbed dose rate of beta rays in free air at KAERI and PNNL are quite similar with each other. As reference devices for the radiation measurement, both laboratories use the air-equivalent plastic-walled ionization chamber for the photon measurement and the PTW extrapolation chamber for beta ray measurement.

The method of the intercomparison is to measure and compare the responses of the PNNL's reference devices calibrated with the U.S. primary standards with those measured by the KAERI's reference devices calibrated with the Korean primary standads at a given distance of KAERI reference radiation fields.

KAERI Reference Photon and Beta radiation Fields[4]

The reference photon irradiation facility at KAERI consists of the gamma-ray and the X-ray irradiation rooms. The dimension of these two irradiation rooms is 5.5 m wide

× 12 m long × 3 m high. The thickness of the concrete shielding wall and ceiling is 0.5 m. The height of the beam line is approximately one meter above the floor. In the gamma irradiation room Cs-137 and Co-60 irradiator(Buchler, Germany) and remotely operating irradiation cart system are established. Table 1 shows the KAERI reference gamma radiation sources.

Table 1. KAERI reference gamma radiation sources

Source	Activity	Reference Date
Cs-137	3.7 GBq (100 mCi)	'91. 9.
	185 GBq (5 Ci)	〃
	3700 GBq (100 Ci)	〃
Co-60	3.7 GBq (100 mCi)	〃

In the X-ray irradiation room, a low energy X-ray generator (0 to 75 kVcp, EG&G Pantak, England), a high energy X-ray generator (0 to 320 kVcp, MG-325, Philips, Germany) and remotely operating irradiation cart system are installed with the X-ray filter system to produce the X-ray beams required for standard irradiation.

As X-rays are not emitted from the R.I. source, the beam quality differs laboratory by laboratory depending on the X-ray generation technique and the adopted metal filters. In order to avoid this problem the U.S.A. adopts an ANSI N13.11 criteria[3] and the ISO defines ISO-4037 criteria[5] as the X-ray beam standard.

KAERI has established different X-ray beams complying with both the U.S. standard (5 beams) and the ISO standard (4 narrow beams and 8 wide beams) from the results of recent study[4]. Table 2 shows the KAERI reference X-ray beams with those of the ANSI N13.11 and the ISO-4037 criteria. Fig. 1, 2 and 3 show the KAERI reference X-ray spectra.

Table 2. KAERI reference X-Ray fields.

ANSI X-ray Beam				
Beam Code	KAERI		ANSI N13.11	
	Eav (keV)	Homogeneity (%)	Eav (keV)	Homogeneity (%)
M30	19.9	63.4	20	64
M60	34.6	68.2	35	68
M100	54.2	74.4	53	73
M150	76.7	87.8	73	89
H150	118.7	95.2	118	95
ISO X-ray Beam (Narrow Series)				
Tube Potential (keV)	KAERI		ANSI N13.11	
	Eav (keV)	Homogeneity (%)	Eav (keV)	Homogeneity (%)
60	48.2	92.1	48	92.3
80	65.3	94.9	65	93.5
100	83.4	93.9	83	94.8
120	100.6	97.1	100	96.6
150	118.3	94.8	118	95.5
200	163.4	98.3	164	98.5
250	207.6	99.1	208	99.2
300	250.2	99.6	250	99.5
ISO X-ray Beam (Wide Series)				
Tube Potential (keV)	KAERI		ANSI N13.11	
	Eav (keV)	Homogeneity (%)	Eav (keV)	Homogeneity (%)
60	45.4	85.8	45	85.7
80	57.1	81.6	58	79.5
110	79.1	90.4	79	86.5
150	104.6	86.6	104	88.6

As for reference beta ray, KAERI has a standard beta rays irradiator(Buchler, Germany) with 4 beta sources certified by the Physikalisch-Technische Bundesansttalt (PTB), Germany[6] and performed a series of test experiments according to the ISO-6980 criteria[7] to maintain its beam quality and performance. Table 3 shows the KAERI reference beta ray sources and their beam qualities. Table 4 shows the result of performance test for Sr/Y-90 beta source (74 MBq) based on the ISO-6980 criteria.

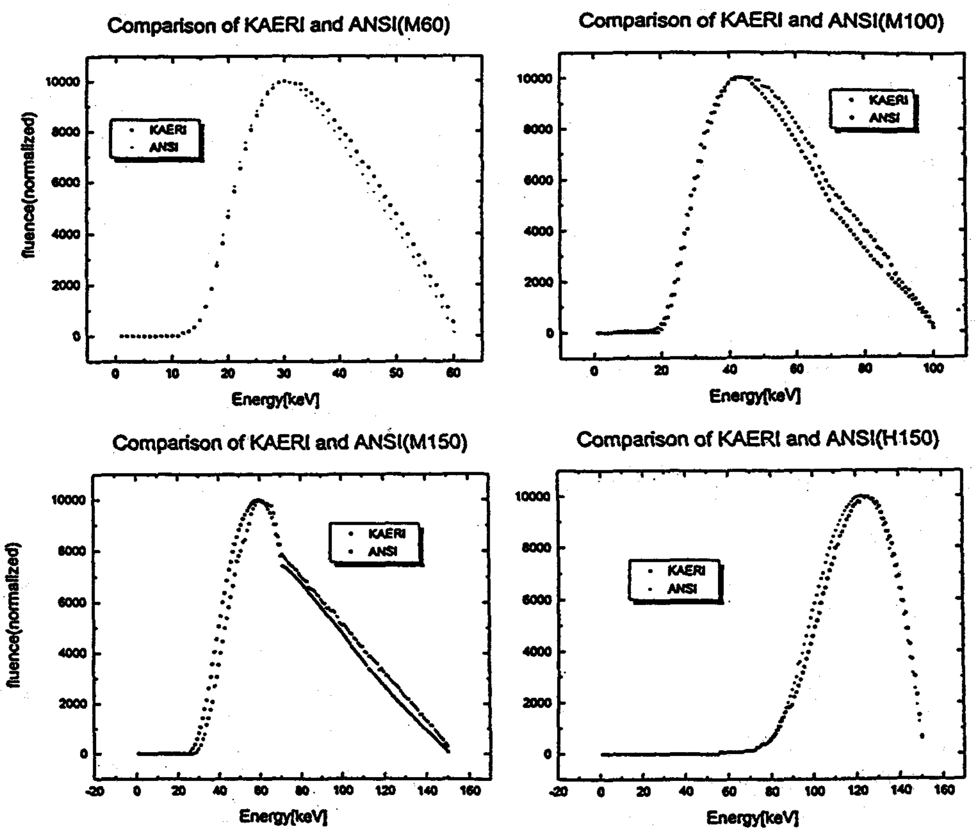

Fig. 1. Comparison of X-ray spectra of KAERI and ANSI.(Unfolded, characteristc peaks are not shown)

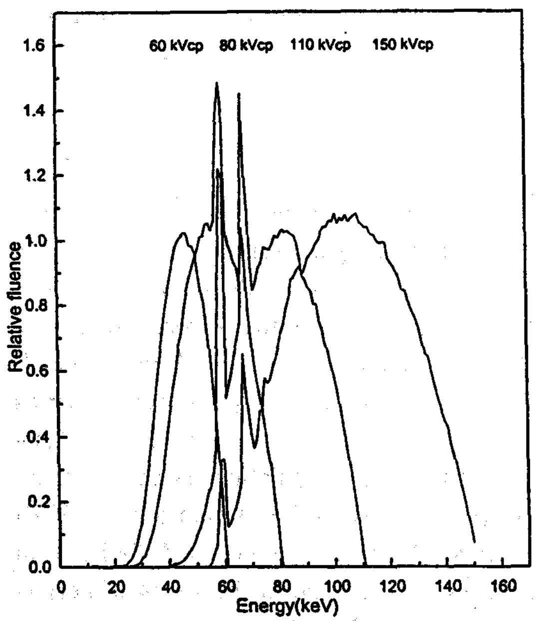

Fig. 2. KAERI X-ray spectra of ISO wide beam series.

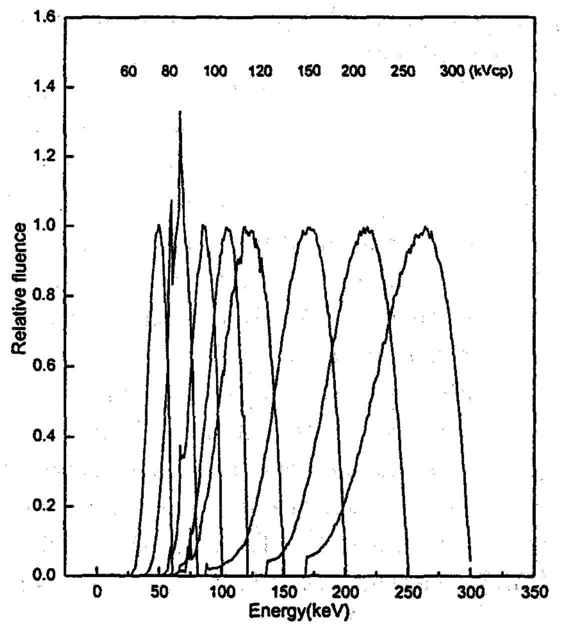

Fig. 3. KAERI X-ray spectra of ISO narrow beam series.

Table 3. KAERI reference beta radiation sources.

Source	Sr/Y-90		Tl-204	Pm-147
Half life(yr)	2.85± 0.8		3.78± 0.04	2.62± 0.02
Emax(MeV)	0.546		0.763	0.225
Eav(MeV)	0.18		0.24	0.06
Activity(MBq)[1)]	74 (3/18/93)	1850 (3/23/93)	18.5 (3/17/93)	518 (3/17/93)
Window thickness (mg/cm^2 Ag-foil)	50± 5		20± 3	5± 1
Beam flattening filter material	No filter		Hostaphan	

[1)] PTB certified

Table 4. Beam quality of KAERI Sr/Y-90 beta source(74 MBq)

Main characteristics	ISO-6980	KAERI
Beam Uniformity		
− X direction	<± 5 %	± 2.08 %
− Y direction	<± 5 %	± 2.41 %
Contribution by Bremsstrahlung radiation	<5 %	2.33 %
Max. residual energy (E_{res})	>1.8 MeV	1.89 MeV

KAERI uses these photon and beta radiation fields in the calibration of various radiation measuring instruments and standard irradiation of domestic personal dosimeters for the performance test based on both the ANSI N13.11 criteria[3] and the Korean technical criteria given as an ordinance by the Ministry of Sciences and Technology[8].

Instruments and Measurement Procedures

The air equivalent plastic walled ionization chamber used by PNNL for photon beam measurement was a Capintec Model PM-30 chamber (volume 30 cm^3) initially calibrated at the NIST. The electrical charge produced in this chamber was measured by a Keithley Model 617 HIQ electrometer. On the other hand KAERI used an Exradin Model A-3 (volume 3.6 cm^3) air equivalent plastic walled ionization chambers with Keithley Model 35617 electrometer. Connection between the chamber, the power supply and the electrometer was made with low noise triaxial cable.

In photon measurement, in order to exclude the possible errors attributable to the variation of environmental conditions and the distance from the photon source, the KAERI and PNNL ionization chamber were placed in turn at the same position from the photon beam source within the collimated beam diameter to measure the exposure rate (and the resulting air-kerma rate), free-in-air. Electrical signals from the respective chambers were recorded automatically by the KAERI and PNNL electrometer, situated at the control consol outside the irradiation room.

The X-rays and beam qualities adopted in the measurement were the American standard X-ray beam codes M30, M60, M100, M 150 and H150 given in the ANSI N13.11 criteria.[4] These X-ray beam codes were chosen because they are currently used in the U.S. National Voluntary Laboratory Accreditation Program (NVLAP) for the proficiency test of personal dosimetry program.

For the measurement of the KAERI reference beta rays, both KAERI and PNNL used her own PTW extrapolation chamber in cross-measuring the absorbed dose rate in a tissue of 7.0 mg/cm^2(which is equivalent Hp(0.07)) at a distance of 30 cm from Sr/Y-90 and Tl-204 beta sources mounted in the PTB standard beta irradiator. The electrical charges produced in the respective chamber were measured by a Keithley Model 642 electrometer as done in photon beam measurement.

Results and Discussions

From the results of photon exposure rate measurements by the reference chamber of KAERI and PNNL, the air kerma rate, free-in-air, was then determined by using the following relationship between the exposure and the air-kerma[9].

$$K_a/X = (W/e)/(1-g) \ [mGy/R]$$

where, K_a is the air kerma, X is the exposure, W/e is the mean energy per unit charge expended in air by electrons(33.97 J/C), and g is the mean fraction of the energy of the secondary electrons which is lost to bremsstrahlung radiation. The values of g and Ka/X used in air kerma determination are given in Table 5.

Table 5. Air Kerma to exposure conversion factor, K_a/X.

Radiation Fields	g-value	K_a/X (mGy/R)
Cs-137	0.0016	8.778
Co-60	0.0032	8.792
X-ray beams	negligible	8.764

Table 6. Photon field intercomparison results between KAERI and PNNL('95).

Photon Beam		Exposure rate (R/hr)		Air Kerma rate(mGy/hr)		KAERI/PNNL
		KAERI	PNNL	KAERI	PNNL	
Cs-137		31.037	30.421	272.443	267.036	1.020
		2.086	2.047	18.311	17.968	1.019
Co-60		0.102	0.100	0.895	0.880	1.017
M30	1 mA	0.491	0.494	4.306	4.330	0.994
	10 mA	1.639	1.648	14.364	14.439	0.995
M60	1 mA	0.127	0.128	1.112	1.158	0.994
	10 mA	1.216	1.227	10.657	10.753	0.991
M100	1 mA	0.126	0.124	1.103	1.086	1.015
	10 mA	1.202	1.184	10.534	10.376	1.015
M150	1 mA	0.149	0.146	1.303	1.282	1.017
	10 mA	1.437	1.412	12.590	12.375	1.017
H150	10 mA	0.0310	0.0312	0.271	0.273	0.994
	20 mA	0.0599	0.0600	0.525	0.526	0.998

The results of exposure rate and resulting air kerma rate appeared in both KAERI and PNNL measurements are given in Table 6. As seen in the table, the results agreed with each other within about ± 2.0 %. The degree of this agreement between KAERI and PNNL results in photon measurement is highly encouraging, when considering both laboratories used different ionization chambers calibrated in different countries.

The results of intercomparison measurement for the KAERI reference Sr/Y-90 and Tl-204 beta radiation are shown in Table 7 together with PTB values and additional measurement results made by the Korean primary calibration laboratory (Korea Research Institute of Standards and Science, KRISS). The differences of beta ray absorbed dose measurement in free air by KAERI, PNNL and KRISS were less than ± 1.0 % which indicated very good agreement with each other.

Table 7. Intercomparison results for KAERI reference beta rays fields('96).

Sources	Absorbed dose rate (μGy/sec)[1)]				KAERI/PNNL
	PTB*	PNNL	KRISS	KAERI	
Sr/Y-90 (74 MBq)	2.633	2.628 (0.998)	2.636 (1.001)	2.627 (0.998)	0.999
Sr/Y-90 (1.85 GBq)	73.573	74.089 (1.007)	–	73.719 (1.002)	0.995
Tl-204 (18.5 MBq)	0.147	–	–	0.148 (1.007)	–

[1)]In a tissue of 7.0 mg/cm² measured at 30 cm distance from the source.

*Decay corrected value.

· Values in parenthesis are the relative ratio to PTB value.

CONCLUSIONS

The calibration uncertainty in the quantity of exposure rate, air kerma rate and absorbed dose rate determined by the national primary calibration laboratory is usually in the range of approximately ± 1.0 % with 95 % confidence level. When this quantity is transferred to a secondary calibration laboratory under the national standard traceability system, it may result in a larger uncertainty of about ± 3.0 %. This means that if all the controls on the transfer of such calibration quantity from primary to secondary laboratory operate perfectly, it would be expected that measurements of exposure rate, air kerma rate and absorbed dose rate by two independent secondary laboratories should agree with each other at least at the level of about ± 3.0 %.

The fact that the results of intercomparison measurement perforemed between KAERI and PNNL for the KAERI reference photon and beta radiation fields agreed within about ± 2.0 % and it was evaluated to be very satisfying. For some of the measurements, the agreements were extremely good within a few tenth of a percent.

This tells that the KAERI reference radiation fields and the beam qualities are well defined and comply well with the international standard. Therefore, the KAERI radiation calibration and dosimetry laboratory will further play an important role as a national basis not only for precise calibration of radiation measuring instruments, standard irradiation of personal dosimeters for performance test, but also for the researches and developments in radiation protection dosimetry area in Korea.

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