Hp(3) Comes into Focus
Views from a Health Physicist

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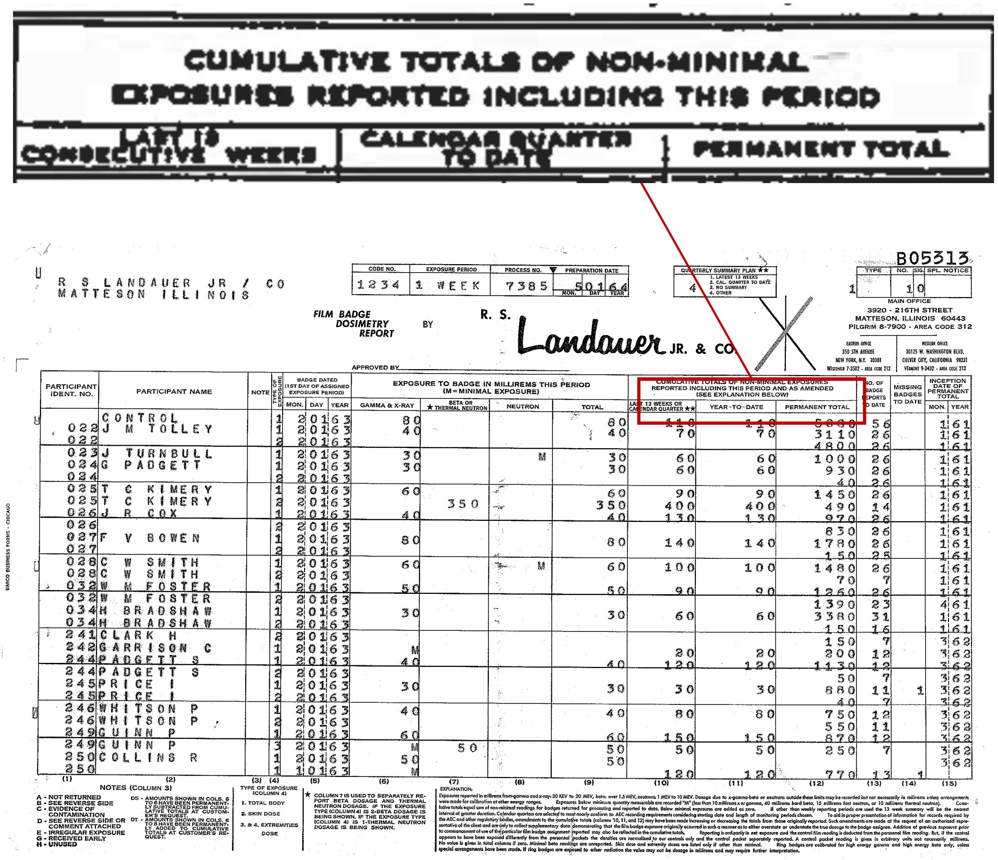
Dose to the Lens of the Eye Symposium
Canadian Nuclear Safety Commission & U.S. Nuclear Regulatory Commission
Ottawa, Canada

October 31, 2018

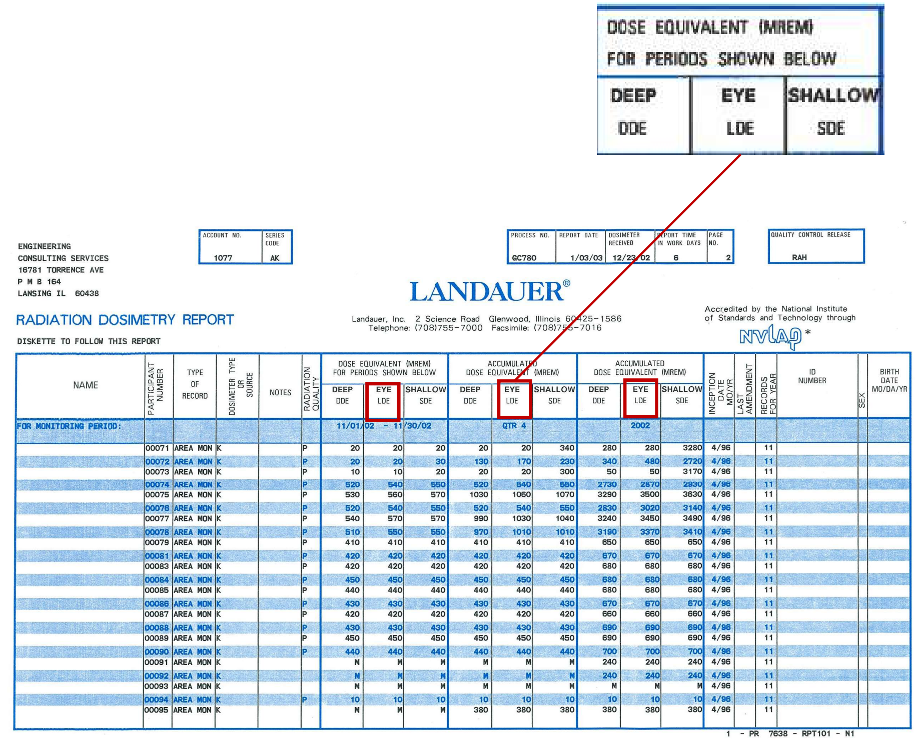
History of Lens of Eye Dose Limits

- President Eisenhower in 1960 through Federal Radiation Council (FRC60b)
  - Federal Radiation Council, Staff Report No. 1, FRC60b, *Background Material for the Development of Radiation Standards*, May 13, 1960.
  - Whole body, head and trunk, active blood-forming organs, gonads or ***lens of the eyes*** are not to exceed 3 rem (0.03 Sv) in 13 consecutive weeks, and the total accumulated dose is limited to 5 rems (50 mSv) multiplied by the number of years beyond age 18, expressed as 5(N-18), where N is the current age
    - Total dose to lens of eye 3 rem (30 mSv) per quarter which also would equal a limit of 12 rem (12 mSv) per year.
    - Effectively considered part of whole body



History of Lens of Eye Dose Limits (cont.)

- 10CFR20 - September 1978 limits whole body, head and trunk, active blood-forming organs, gonads or ***lens of the eyes*** to 1.25 rem (12.5 mSv) per quarter and 5 rem (50 mSv) per year.
  - Landauer starts referencing new limits in 1980 on Radiation Dosimeter Reports.
- 10CFR20 - May 1991 NRC adopted ICRP 26 recommendations and separate lens of eye limit established at 15 rem (150 mSv) per year.[2]
  - 1994 Landauer starts reporting lens dose equivalent (LDE) on Radiation Dosimeter Reports


DOSE EQUIVALENT (MREM) FOR PERIODS SHOWN BELOW

DEEP DDE	EYE LDE	SHALLOW SDE

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DISKETTE TO FOLLOW THIS REPORT

NAME	PARTICIPANT NUMBER	TYPE OF RECORD	DOSIMETER TYPE OR SOURCE	NOTES	RADIATION QUALITY	DOSE EQUIVALENT (MREM) FOR PERIODS SHOWN BELOW DEEP DDE	EYE LDE	SHALLOW SDE	ACCUMULATED DOSE EQUIVALENT (MREM) DEEP DDE	EYE LDE	SHALLOW SDE	ACCUMULATED DOSE EQUIVALENT (MREM) DEEP DDE	EYE LDE	SHALLOW SDE	INCEPTION DATE MO/YR	LAST AMENDMENT	RECORDS FOR YEAR	ID NUMBER	SEX	BIRTH DATE MO/DA/YR
FOR MONITORING PERIOD:						11/01/02 - 11/30/02				QTR 4			2002							
	00071	AREA MON	K		P	20	20	20	20	20	340	280	280	3280	4/96		11			
	00072	AREA MON	K		P	20	20	30	130	170	230	340	480	2720	4/96		11			
	00073	AREA MON	K		P	10	10	20	20	20	300	50	50	3170	4/96		11			
	00074	AREA MON	K		P	520	540	550	520	540	550	2730	2870	2930	4/96		11			
	00075	AREA MON	K		P	530	560	570	1030	1060	1070	3290	3500	3630	4/96		11			
	00076	AREA MON	K		P	520	540	550	520	540	550	2830	3020	3140	4/96		11			
	00077	AREA MON	K		P	540	570	570	990	1030	1040	3240	3450	3490	4/96		11			
	00078	AREA MON	K		P	510	550	550	970	1010	1010	3190	3370	3410	4/96		11			
	00079	AREA MON	K		P	410	410	410	410	410	410	650	650	650	4/96		11			
	00081	AREA MON	K		P	420	420	420	420	420	420	670	670	670	4/96		11			
	00083	AREA MON	K		P	420	420	420	420	420	420	680	680	680	4/96		11			
	00084	AREA MON	K		P	450	450	450	450	450	450	680	680	680	4/96		11			
	00085	AREA MON	K		P	440	440	440	440	440	440	680	680	680	4/96		11			
	00086	AREA MON	K		P	430	430	430	430	430	430	670	670	670	4/96		11			
	00087	AREA MON	K		P	420	420	420	420	420	420	660	660	660	4/96		11			
	00088	AREA MON	K		P	430	430	430	430	430	430	690	690	690	4/96		11			
	00089	AREA MON	K		P	450	450	450	450	450	450	690	690	690	4/96		11			
	00090	AREA MON	K		P	440	440	440	440	440	440	700	700	700	4/96		11			
	00091	AREA MON	K			M	M	M	M	M	M	240	240	240	4/96		11			
	00092	AREA MON	K			M	M	M	M	M	M	240	240	240	4/96		11			
	00093	AREA MON	K			M	M	M	M	M	M	M	M	M	4/96		11			
	00094	AREA MON	K		P	10	10	10	10	10	10	10	10	10	4/96		11			
	00095	AREA MON	K			M	M	M	380	380	380	380	380	380	4/96		11			

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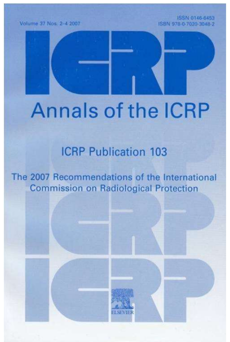
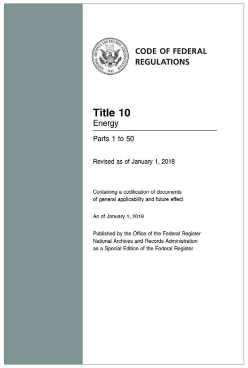
Lens of Eye Dose Limits Evolving

- ICRP 103 lens dose limit of 2 rem (20 mSv) per year averaged over 5 years and currently in effect in European Union (EU)
  - ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37(2–4).
- NRC proposed to reduced lens of eye dose limit from 15 rem (150 mSv) to 5 rem (50 mSv) per year
  - Federal Register, NRC Radiation Protection - 10CFR20, Volume 79, Number 143, July 2014
- Current 10CFR20 lens dose limit of 15 rem (150 mSv)





Lens Dose Equivalent Paradox

- Occupational dose limit for shallow *Hp*(0.07) , lens *Hp*(3), and deep *Hp*(10) defined in 10CFR20.1201
  - Shallow dose equivalent is defined as the personal dose equivalent at a depth of 0.07 mm in ICRU tissue and is denoted by *H*p(0.07).
  - Deep dose equivalent is defined as the personal dose equivalent at a depth of 10 mm in ICRU tissue and is denoted by *H*p(10).
  - Lens dose equivalent at the depth of 3 mm and denoted by *H*p(3)
- Coefficients (C_k factors) exists to Convert from Air Kerma to Deep and Shallow Personal Dose Equivalent but not for Lens Dose Equivalent
  - Multiplying kerma (K_a) by the conversion coefficient (C_k) yields the personal dose equivalent
- C_k factors did not exists for lens of eye so how do you comply with 10CRF20?

Inconsistency in 10CFR20 and NVLAP (ANSI N13.11-2009)

- 10CFR20.1501
  - (d) All personnel dosimeters (except for direct and indirect reading pocket ionization chambers and those dosimeters used to measure the dose to the extremities) that require processing to determine the radiation dose and that are used by licensees to comply with § 20.1201, with other applicable provisions of this chapter, or with conditions specified in a license must be processed and evaluated by a dosimetry processor—
    - (1) Holding current personnel dosimetry accreditation from the National Voluntary Laboratory Accreditation Program (NVLAP) of the National Institute of Standards and Technology; and
    - (2) Approved in this accreditation process for the type of radiation or radiations included in the NVLAP program that most closely approximates the type of radiation or radiations for which the individual wearing the dosimeter is monitored.
- National Voluntary Laboratory Accreditation Program (NVLAP) does not accredit dosimetry systems for lens dose equivalent. How does a licensee comply?

Landauer's Approach to LDE before C_k was Introduced

- Landauer dosimetry algorithms estimate *H*p(3) from *H*p(0.07) and *H*p(10) [2 & 3]
- Using the NIST *H*p(3) data contained in a paper by Soares and Martin, a function was derived to allow calculation of lens-of-eye dose using shallow and deep dose values. [4]
  - The paper contains air kerma to dose correction factors for the three depths of interest for 21 of the photon fields
  - The function can also be used to calculate the *H*p(3) dose directly from the *H*p(0.07) and *H*p(10) dose values

$$Hp(3) = Hp(0.07) * \left\{1.4 - \left(1.04 * e^{-\left[\frac{Hp(10)}{Hp(0.07)}\right]}\right)\right\}$$

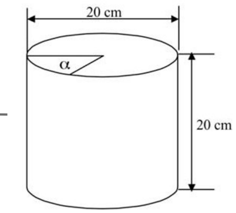
Equation 1: *Hp*(3) as a Function of *Hp*(10) and *Hp*(0.07)

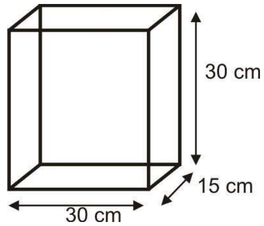
Landauer's Approach to LDE before C_k (cont.)

- Photon Dose
  - For low to medium energy photons, the 300 mg/cm^2 or *Hp*(3) dose is calculated using this function, Equation 1.
  - Photons greater than 60 keV, the lens-of-eye photon dose is equivalent to *H*p(10)
- Beta Dose
  - *H*p(3) is set equal to the calculated *H*p(0.07) for the weakly penetrating ^{85}Kr
  - *H*p(3) approximately 45% to 50% of *Hp*(0.07) for the more penetrating ^{90}Sr or depleted uranium
- Neutron Dose
  - *H*p(3) is set equal to the neutron *H*p(10)
- Total *H*p(3)
  - The contribution of the photon, beta, and neutron dose are summed to arrive at the total *H*p(3)

C_k Debate Emerges

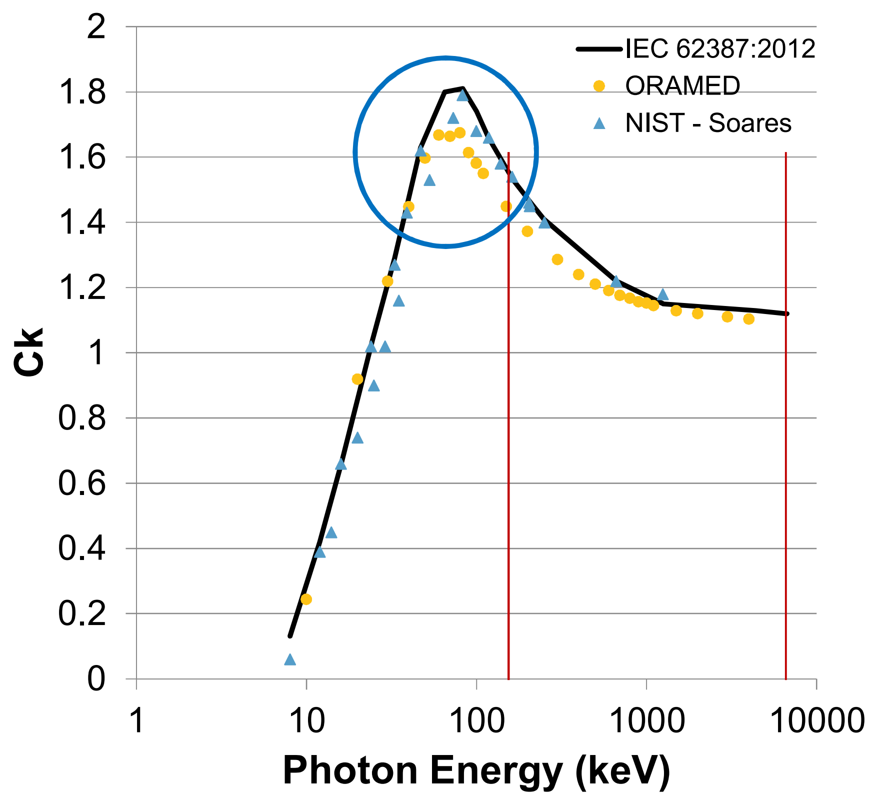
- C_k factors dependent on phantoms
  - ORAMED project (Optimization of RAdiation protection for MEDical) for eye lens dosimetry
    - ORAMED: Optimization of Radiation Protection of Medical Staff, F. Vanhavere, 2011
    - 20 cm high x 20 cm diameter cylinder
    - Water filled
    - Work started in 2008
  - Physikalisch-Technische Bundesanstalt (PTB) 2011
    - 30 cm x 30 cm x 15 cm slab
    - Water filled
    - Work started in 2012
  - PTB 2015
    - 20 cm high x 20 cm diameter cylinder
    - Water filled
- Which C_k factors to use?
  - ISO 4037-3 has both but cylindrical phantom preferred
  - IEC 62387 adopted cylindrical phantom due to issues noted with slab phantom at large angles





Comparison of Various C_k Factors for *H*p(3)

- Ck factors from ISO 4037 / IEC 62387 and NIST-Soares data
  - Close for Nuclear Power Plant (NPP) fields.
  - Less than 4% off for typical medical fields or 80 kVp (40 keV) to 120 kVp (60 keV)
- Cylindrical phantom derived Ck are lower
- NPP clients should experience lower *Hp*(3) doses after moving to cylindrical phantom derived algorithms.



International Electrotechnical Commission (IEC) to the Rescue

- IEC TC45/SC45B/WG14
- IEC 62387:2012 used for type testing dosimeters
- No agreed upon *H*p(3) C_k conversion factors internationally until IEC 62387:2012
  - Technically no agreed upon method to calculate the lens dose
  - C_k factors based on Physikalisch-Technische Bundesanstalt (PTB) data [6]
  - Dose conversion factors defined on slab phantom for *H*p(3) in conflict with ORAMED
  - Slab phantom is widely used and available in many calibration laboratories
- However, false start and revised to adopt cylindrical phantom Ck for *Hp*(3)


IEC

IEC 62387

Edition 1.0 2012-12

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Radiation protection instrumentation – Passive integrating dosimetry systems for personal and environmental monitoring of photon and beta radiation

Instrumentation pour la radioprotection – Systèmes dosimétriques intégrés passifs pour la surveillance de l'individu et de l'environnement des rayonnements photoniques et bêta

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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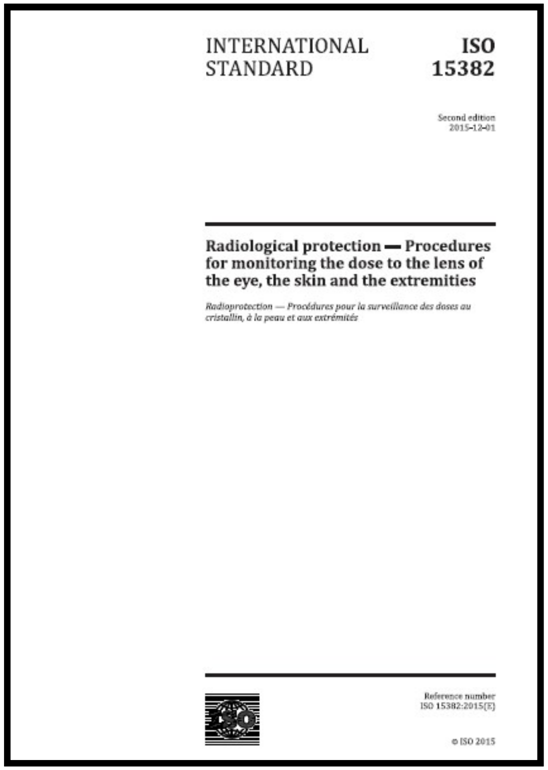
International Organization for Standardization ISO 15382:2015

- ISO/TC85/SC2/WG19
- Provides procedures for monitoring the dose to the skin, the extremities, and the lens of the eye.
- Provides guidance on determining when lens of eye dosimeter is needed.
- Provides guidance on the positioning of the dosimeter.
- Precursor to IAEA TechDoc 1731
- Recommends following ISO 4037 for Ck and does not take a side in the phantom debate.


INTERNATIONAL STANDARD

ISO 15382

Second edition
2015-12-01

Radiological protection — Procedures for monitoring the dose to the lens of the eye, the skin and the extremities

Radioprotection — Procédures pour la surveillance des doses au cristallin, à la peau et aux extrémités

Reference number
ISO 15382:2015(E)

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IAEA TECHDOC 1731

- Provides easy to follow flow chart for determining if lens of eye dose monitoring is required

TABLE 3. DOSES DUE TO PHOTON RADIATION

<table>
<tr><th>Impact factor</th><th colspan="3">Comment</th></tr>
<tr><td rowspan="4">A
(Energy and angle)</td><td colspan="3">Is the mean photon energy below about 40 keV?</td></tr>
<tr><td rowspan="3">If yes
↓
$H_p(0.07)$ may be used but not $H_p(10)$ (see Fig. 6 in Ref. [65] and Fig. 1 in Ref. [66])</td><td colspan="2">If no
↓
Is the radiation coming mainly from the front or is the person moving in the radiation field?</td></tr>
<tr><td>If yes
↓
$H_p(0.07)$ or $H_p(10)$ may be used (see Fig. 1 in Ref. [66])</td><td>If no
↓
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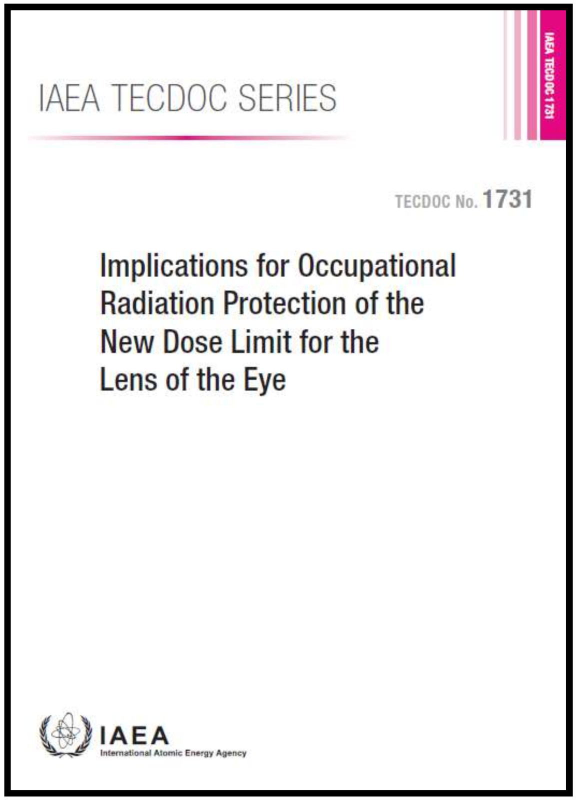
<tr></tr>
<tr><td rowspan="2">B
(Geometry)</td><td colspan="3">Are homogeneous radiation fields present?</td></tr>
<tr><td>If yes
↓
Monitoring on the trunk may be used.</td><td colspan="2">If no
↓
Monitoring near the eyes is necessary.</td></tr>
<tr><td rowspan="2">C
(Protective equipment)</td><td colspan="3">Is protective equipment such as lead glasses, ceiling, table shields, and lateral suspended shields in use?</td></tr>
<tr><td>If used for the eye
↓
Monitoring near the eyes and below the protective equipment or below an equivalent layer of material is necessary. Otherwise, appropriate correction factors to take the shielding into account should be applied.</td><td colspan="2">If used for the trunk (e.g. a lead apron)
↓
Monitoring below the shielding underestimates the dose to the lens of the eye as the eye is not covered by the trunk shielding.
↓
Separate monitoring near the eyes is necessary.</td></tr>
</table>

- Provides guidance on when *H*p(0.07) and/or *H*p(10) can be used as a surrogate for *H*p(3)



IAEA TECHDOC 1731 Flow Chart for Monitoring

1 Radiation Field Characteristics

2 Uniformity of the Field

3 Shielding

TABLE 3. DOSES DUE TO PHOTON RADIATION

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<tr><th>Impact factor</th><th colspan="3">Comment</th></tr>
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↓
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↓
Separate monitoring near the eyes is necessary.</td></tr>
</table>

IAEA TECDOC 1731 – Photon NPP

- Example PWR Steam Generator Jumper (nozzle dam technicians)
  - Activated corrosion products Co-58 and Co-60 dominate the radiation field.[7]
  - Photon Energy ranges from 511 keV to 1675 keV

Streaming radiation field creates non-uniform irradiation to the head.

Dosimeter on the chest and no eye protection.

ANSI/HPS N13.41-2011, *Criteria for Performing Multiple Dosimetry*, would drive the use of 7 dosimeters.

TABLE 3. DOSES DUE TO PHOTON RADIATION

Impact factor	Comment		
A (Energy and angle)	Is the mean photon energy below about 40 keV?		
	If yes ↓ $H_p(0.07)$ may be used but not $H_p(10)$ (see Fig. 6 in Ref. [65] and Fig. 1 in Ref. [66])	If no ↓ Is the radiation coming mainly from the front or is the person moving in the radiation field?	
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B (Geometry)	Are homogeneous radiation fields present?		
	If yes ↓ Monitoring on the trunk may be used.	If no ↓ Monitoring near the eyes is necessary.	
C (Protective equipment)	Is protective equipment such as lead glasses, ceiling, table shields, and lateral suspended shields in use?		
	If used for the eye ↓ Monitoring near the eyes and below the protective equipment or below an equivalent layer of material is necessary. Otherwise, appropriate correction factors to take the shielding into account should be applied.	If used for the trunk (e.g. a lead apron) ↓ Monitoring below the shielding underestimates the dose to the lens of the eye as the eye is not covered by the trunk shielding. ↓ Separate monitoring near the eyes is necessary.	

IAEA TECDOC 1731 – Photon Medical

- Example Fluoroscopy Procedure [8]
  - Approximately 40 keV (80 kVp) photon field.

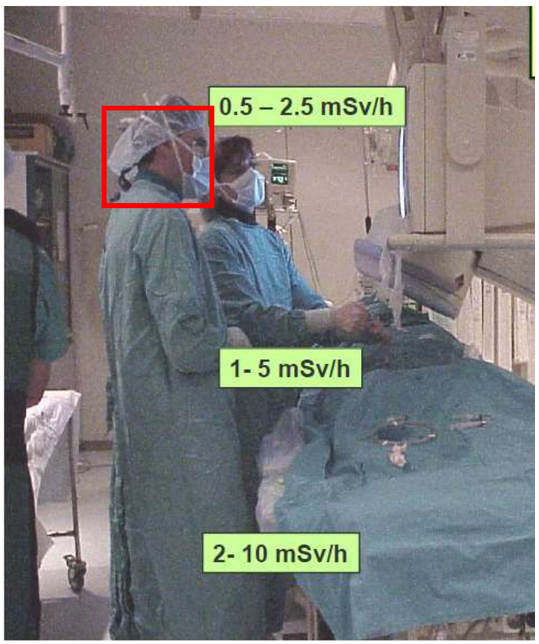

TABLE 3. DOSES DUE TO PHOTON RADIATION

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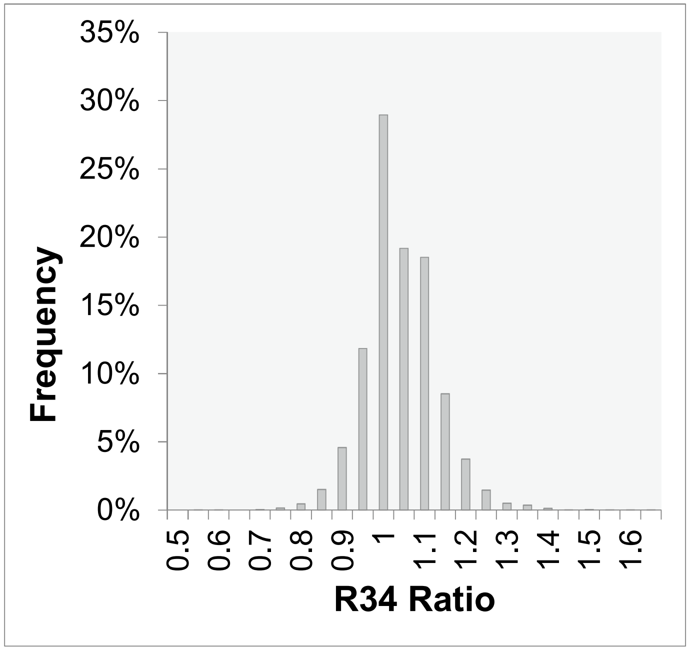
ISO and IAEA Method for Assigning *H*p(3)

- ISO and IAEA recommend using *H*p(0.07) and/or *H*p(10) as a surrogate for *H*p(3) in certain environments
  - Radiation source mainly from the front of the worker recommends *H*p(0.07) or *H*p(10)
    - Results in a 0.05% higher dose if *H*p(10) used instead of the LDR Calculated *H*p(3) in Equation 1.
    - Results in -1.5% lower dose if *H*p(0.07) is used instead of LDR *H*p(3).
  - Radiation in multiple directions to the worker *H*p(10) should be used
    - Results in a 0.05% higher dose than the Landauer *H*p(3) calculation.

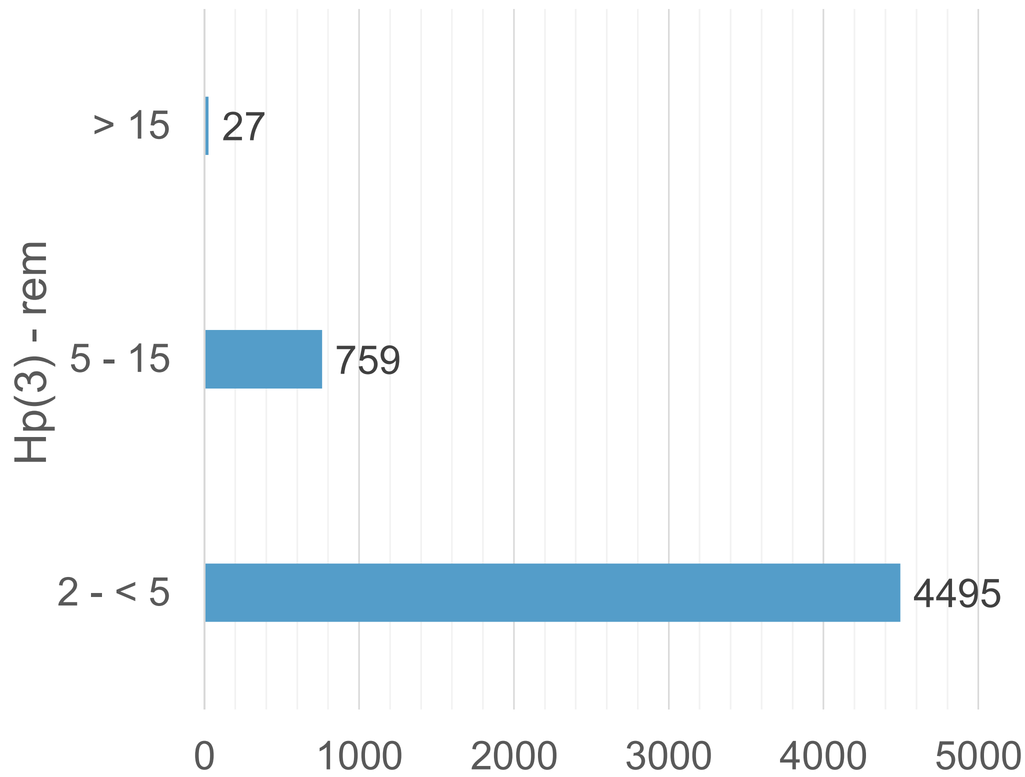
InLight LDR Model 2 Dosimeter Data in Nuclear Power Plant (NPP) Environment

- 26,000 InLight LDR Model 2 dosimeter results from NPP environment were studied [9]
  – No beta response observed 100% photon only readings
- Dosimeters can be used as crude spectrometer and energy can be estimated based on the ratio of response of Element 3(Al) : Element 4 (Cu) = R34
- R34 falls between 1.020 to 1.023, 95% of the time which indicates photons greater than 250 keV
- A lens of eye dose algorithm using cylindrical Ck factors instead of the LDR approach would not have much impact in NPP radiation environments (1% to 5%)
  – Main dose component are photons above 250 keV
  – If beta field is suspected the lens of eye tends to be protected by respiratory protection
  – Non-uniform fields encountered multiple dosimeters deployed
  – Work controlled by Radiological Work Permit (RWP) and working conditions well known



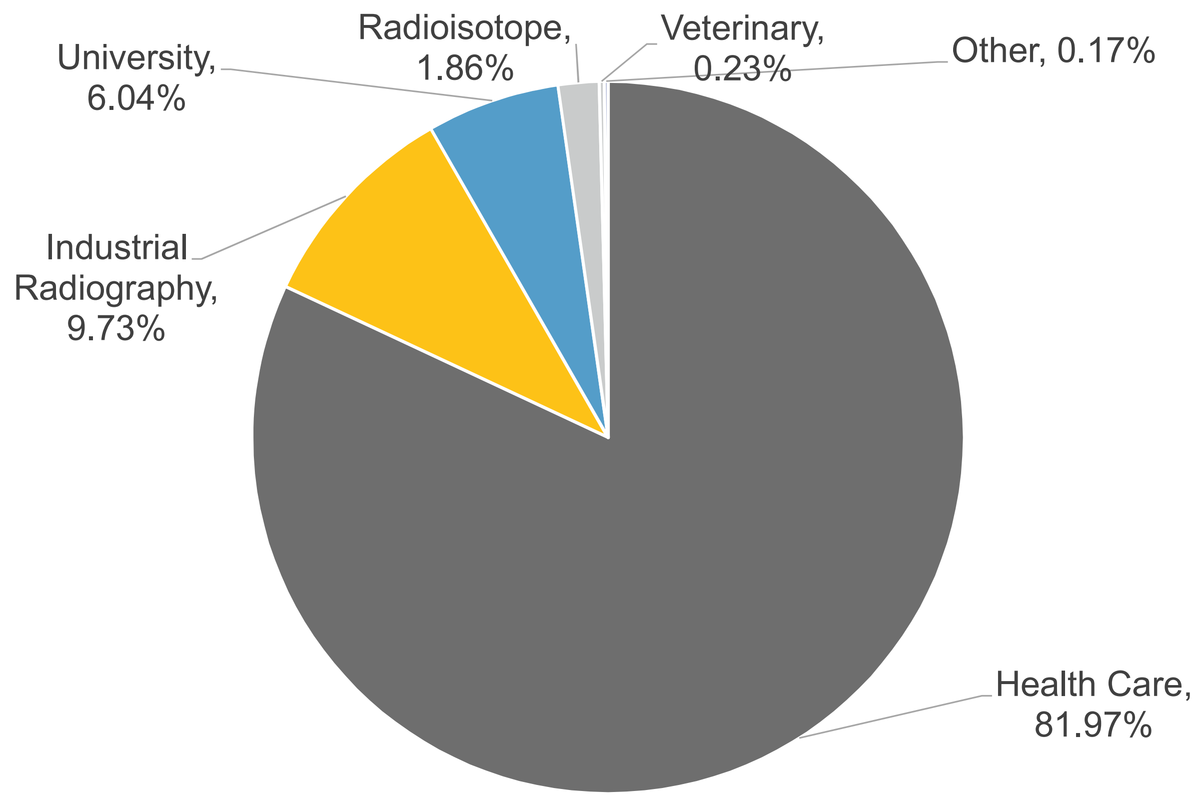
2017 *Hp*(3) Data from Landauer Repository

- 5281 workers exceeded 2 rem (20 mSv) in 2017
  - ICRP 103 lens dose limit of 2 rem (20 mSv) per year averaged over 5 years and currently in effect in Europe [12]
- 786 workers exceeded 5 rem (50 mSv) in 2017
  - NRC proposed to reduced lens of eye dose limit from 15 rem (150 mSv) to 5 rem (50 mSv) per year [13]
- 27 workers exceeded 15 rem (150 mSv) in 2017
  - Current 10CFR20 lens dose limit of 15 rem (150 mSv) [14]



Industry Segments with *Hp*(3) > 2 rem (20 mSv)

- Health Care, Industrial Radiography, University, Radioisotope, Veterinary, and Other (Transportation, Dental, and Research) are Industry Segments with doses greater than 2 rem (20 mSv)
  - University data might be closely associated with Health Care which would make it 88% of the total.

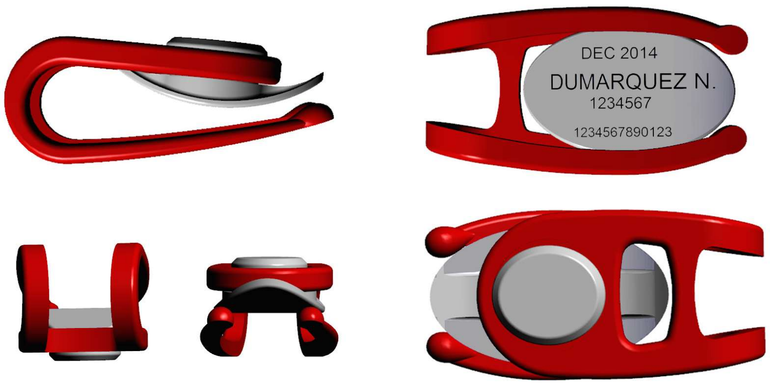


27 Participants >15 rem (150 mSv) by Occupation

Occupation	% of the Total >15 rem
Industrial Radiography	14.8%
Pain Management - Rehab	14.8%
Radiology - diagnostic radiology	14.8%
Vascular Surgery	14.8%
Interventional Radiology	7.4%
Cardiologist	3.7%
Clinical Psychologist	3.7%
Obstetrics & Gynecology	3.7%
PET Research Pediatrics and Tuberculosis	3.7%
Psychiatry & Neurology	3.7%
Radioisotope	3.7%
Security Threat Detection Research	3.7%
Speech-Language Pathologist	3.7%
Dental Implants	3.7%

- Categorized workers into disciplines using series codes and internet search
- Top 5 Occupations >15 rem (150 mSv)
  - Industrial Radiography (4)
  - Pain Management – Rehab (4)
  - Diagnostic Radiology (4)
  - Vascular Surgery (4)
  - Interventional Radiology (2)
- The remaining contained some interesting occupations
  - Researcher using 18F-FDG positron emission tomography (PET) scans to determine if tuberculosis treatment is working or drug resistant.
  - Psychiatrist specializing in cancer patients
  - Speech Pathologist using video-assisted fluoroscopy of swallowing (VFSS)
  - Dental implants

VISION Lens Dosimeter



- Measures *H*p(3) close to the eye
- Mounts on safety glasses
- Meets IEC 62387 verified by 3rd party [10]
  - Irradiations conducted at Laboratoire National Henri Becquerel (LNHB)
  - This version is based on LiF TLD technology and Landauer is working on Al_2O_3:C OSL version

$$Hp(3) = 1.008*[(R - BL) / (CF * SF)] - BG$$

R= Reader output in counts,
BL= counts obtained from process Blank TLD dosimeters,
CF=Calibration Factor of reader in Counts/mrem.
SF= Sensitivity Factor for chip determined at the time of analysis
BG = Ambient Background Radiation

Conclusions

- Dose limit in US currently 15 rem but will be reduced.
  - Will we settle on 2 or 5 rem?
- Contradictions in ISO and IEC standards have been resolved.
  - C_k factors exits now to enable calculation of Hp(3) but ANSI N13.11 has not addressed Hp(3).
- Landauer data shows 5281 workers exceeded Hp(3) of 2 rem in 2017
  - 27 of which exceeded the federal limit of 15 rem for Hp(3)
- Landauer data shows health care industry leads the way with the number of workers with Hp(3) dose > 2 rem.
  - 82% and could be as high as 88% when considering universities.
  - This can be even more troubling considering non-uniform fields and complication of dosimeter placement.
- Health care industry will see significant impact if dose limits are reduced with key medical staff members exceeding lens of eye dose threshold regardless if 2 or 5 rem is adopted.
  - Credit for PPE and shielding similar to Webster effective dose equivalent calculations may be needed going forward.
- Health care industry will see significant impact if dose limits are reduced with key medical staff members exceeding limits if additional PPE or engineering controls are not implemented.
- 67% reduction noticed in the number of people exceeding Hp(3) annual limit as compared to the average that exceed in 2014, 2015, and 2016. Data from 2017 NRC Regulatory Information Conference
- Some surprises were noted on occupations with high Hp(3). Can't always assume….

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Questions

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