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Hp(3) Comes into Focus

Views from a Health Physicist

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2017 NRC Regulatory Information Conference

Dose to the Lens of the Eye – the Latest Scientific Recommendations

March 15, 2017

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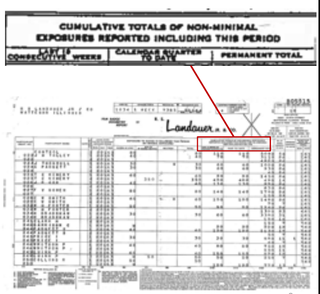
History of Lens of Eye Dose Limits in US Nuclear Power

- President Eisenhower in 1960 through Federal Radiation Council (FRC60b)[1]
  - Whole body, head and trunk, active blood-forming organs, gonads or ***lens of the eyes*** are not to exceed <u>3 rem (0.03 Sv) in 13 consecutive weeks</u>, and the total accumulated dose is limited to 5 rems (0.05 Sv) 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 (0.03 Sv) per quarter which also would equal a limit of 12 rem (0.12 Sv) per year.
    - Effectively considered part of whole body



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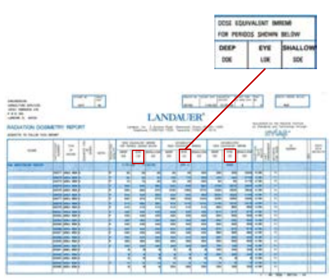
History of Lens of Eye Dose Limits in US Nuclear Power (cont.)

- 10CFR20 - September 1978 limits whole body, head and trunk, active blood-forming organs, gonads or ***lens of the eyes*** to 1.25 rem (0.0125 Sv) per quarter and 5 rem (0.05 Sv) 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 (0.15 Sv) per year.
  - 1994 Landauer starts reporting lens dose equivalent (LDE) on Radiation Dosimeter Reports



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Proposed 10CFR20 Change

- NRC proposed reduced lens of eye dose limit from 15 rem (0.15 Sv) to 5 rem (0.05 Sv) per year
- NRC recommendation not in line with ICRP 118 lens dose limit of 2 rem (0.02 Sv) per year averaged over 5 years

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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 *Hp*(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 *Hp*(10).
  - Lens dose equivalent at the depth of 3 mm and denoted by *Hp*(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?

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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?

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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)

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

- Photon Dose
  - For low to medium energy photons, the 300 mg/cm² 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 *Hp*(10)
- Beta Dose
  - *Hp*(3) is set equal to the calculated *Hp*(0.07) for the weakly penetrating ^{85}Kr
  - *Hp*(3) approximately 45% to 50% of *Hp*(0.07) for the more penetrating ^{90}Sr or depleted uranium
- Neutron Dose
  - *Hp*(3) is set equal to the neutron *Hp*(10)
- Total *Hp*(3)
  - The contribution of the photon, beta, and neutron dose are summed to arrive at the total *Hp*(3)

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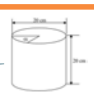
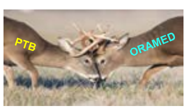
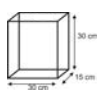
C_k Debate Emerges

- C_k factors dependent on phantoms
  - ORAMED project (Optimization of RAdiation protection for MEDical) for eye lens dosimetry [5]
    - 20 cm high x 20 cm diameter cylinder
    - Water filled
    - Work started in 2008
  - 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 4037-3:2016 draft has both but cylindrical phantom preferred
  - IEC 62387:2012 will be modified to adopt cylindrical phantom
  - Issues with slab phantom at large angles







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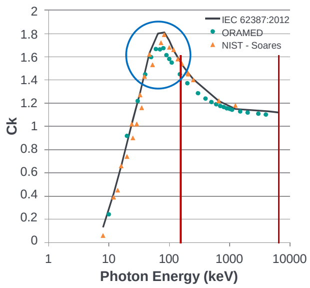
Comparison of Various C_k Factors for *Hp*(3)

- Ck factors from 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.



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International Electrotechnical Commission (IEC) to the Rescue

- IEC TC45/SC45B/WG14
- IEC 62387:2012 used for type testing dosimeters
- No agreed upon *Hp*(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 *Hp*(3) in conflict with ORAMED
  - Slab phantom is widely used and available in many calibration laboratories
- However, false start and will be changed to adopt cylindrical phantom Ck for *Hp*(3)


IEC 62387

INTERNATIONAL STANDARD

NORME 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

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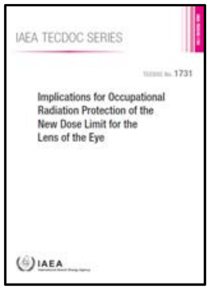
IAEA TECHDOC 1731

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

TABLE 3: DOSES DUE TO PHOTON RADIATION

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



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IAEA TECHDOC 1731 Flow Chart for Monitoring

Radiation Field Characteristics

Uniformity of the Field

Shielding

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?	
		If yes ↓ $H_p(0.07)$ or $H_p(10)$ may be used (see Fig. 1 in Ref. [66])	If no ↓ $H_p(0.07)$ may be used but not $H_p(10)$ (see Fig. 1 in Ref. [66])
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.	

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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

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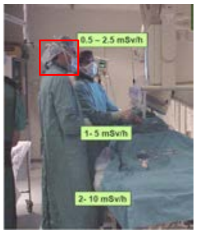
IAEA TECDOC 1731 – Photon Medical

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



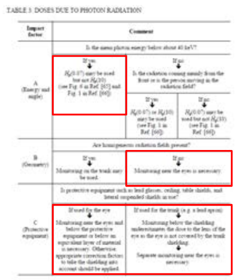


TABLE 3. DOSES DUE TO PHOTON RADIATION

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?	
		If yes: $H_p(0.07)$ or $H_p(10)$ may be used (see Fig. 1 in Ref. [66])	If no: $H_p(0.07)$ may be used but not $H_p(10)$ (see Fig. 1 in Ref. [66])
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	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.	

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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.

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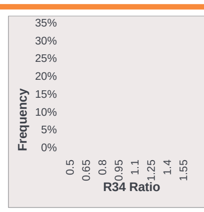
InLight LDR Model 2 Dosimeter Data in Nuclear Power Plant (NPP) Environment

- 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



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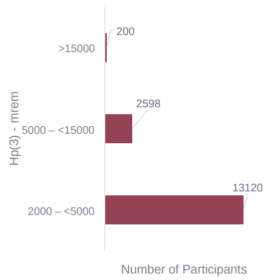
2014 – 2016 Hp(3) Data from Landauer Repository

- 15918 participants have exceeded 2000 mrem (20 mSv) over a 3 year period
  - 9887 unique participants were identified

exceeding has remained fairly consistent year over year by industry and job classification over the three year period.



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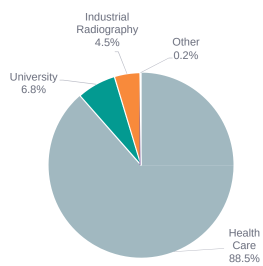
Industry Segments with *Hp*(3) > 5 rem

- Health Care, University, Industrial Radiography, and Other (Radiopharmaceutical, Veterinarian, and Well Logging) are industry Segments with doses greater than 5 rem (50 mSv)
  - University doses data could be included in the Health Care segment.



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Health Care Participants >15 rem by Discipline

Health Care Discipline	% of the Total >15 rem
Radiology & Diagnostic Imaging	20.8%
Vascular Imaging	11.0%
Vascular Surgery	11.0%
Undefined	9.7%
Surgery	7.8%
Pain Management	7.1%
Cardiology	7.1%
Oncology & Radiation Therapy	5.8%
Cardiac Catheterization	4.5%
Gastroenterology	3.9%
Health Care Industry Representative	3.2%
Neurosurgery	2.6%
Anesthesiology	1.9%
Medical Physicist	1.3%
Computerized Tomography	1.3%
Nuclear Medicine	0.6%

- Categorized workers into disciplines using series codes and internet search
  - *Hp*(3) >15 rem (150 mSv) in 2014, 2015, and 2016
- Top 3 Disciplines with participants >15 rem:
  - If cardiac and vascular related disciplines are combined this group has the highest number of participants >15 rem at 33.8%
  - Radiology & Diagnostic was 20.8%
  - Pain Management came in 3rd at 7.1%.

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VISION Lens Dosimeter

$Hp(3)$ = 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

- Measures *Hp*(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

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