Radiation Cataract

Norman J. Kleiman, Ph.D.
Eye Radiation and Environmental Research Laboratory

Department of Environmental Health Sciences
Mailman School of Public Health
Columbia University
Prior to 2011, eye exposure guidelines were based on the view that radiation cataract is a “deterministic” event with a relatively high threshold radiation dose.
Establishing an accurate dose threshold, if any, for potential eye damage is critical for radiation risk assessment and exposure guidelines.
The purpose of radiation protection is to prevent deterministic events of clinical significance and limit stochastic effects to levels that are acceptable, given societal concerns.
Biological Effects

- **Deterministic Effects** – Thresholds
  - e.g., cell killing. Occurs above a certain dose below which, the effect does not occur e.g. erythema (skin reddening), radiation burns.

- **Stochastic Effects** – Probability increases with dose
  - e.g., cell transformation, carcinogenesis.

*Radiation cataract?*
Statement on Tissue Reactions
Approved by the Commission on April 21, 2011

(1) The Commission issued new recommendations on radiological protection in 2007 (ICRP, 2007), which formally replaced the Commission’s 1990 Recommendations (ICRP, 1991a). The revised recommendations included consideration of the detriment arising from non-cancer effects of radiation on health. These effects, previously called deterministic effects, are now referred to as tissue reactions because it is increasingly recognised that some of these effects are not determined solely at the time of irradiation but can be modified after radiation exposure.
(2) The Commission has now reviewed recent epidemiological evidence suggesting that there are some tissue reaction effects, particularly those with very late manifestation, where threshold doses are or might be lower than previously considered. For the lens of the eye, the threshold in absorbed dose is now considered to be $0.5 \text{ Gy}$. 

(3) For occupational exposure in planned exposure situations the Commission now recommends an equivalent dose limit for the lens of the eye of $20 \text{ mSv}$ in a year, averaged over defined periods of 5 years, with no single year exceeding $50 \text{ mSv}$. 

Annals ICRP 2012; 41: 1-322
## History of ICRP Recommendations for Radiation Dose Limits to the Lens

<table>
<thead>
<tr>
<th></th>
<th>Annual exposure limit</th>
<th>Putative Cataract threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRP 1977</td>
<td>300 mSv</td>
<td>15 Sv</td>
</tr>
<tr>
<td>ICRP 2007</td>
<td>150 mSv</td>
<td>5 Sv acute/8 Sv protracted</td>
</tr>
<tr>
<td>ICRP 2012</td>
<td>20 mSv</td>
<td>500 mGy (acute/protracted/chronic)</td>
</tr>
</tbody>
</table>
IAEA Safety Standards
for protecting people and the environment

Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2014
National Council on Radiation Protection and Measurements Commentary Number 26: Impact of Revised Guidance on Radiation Protection for the Lens of the Eye

Lawrence T. Dauer, PhD, Nobuyuki Hamada, PhD, Eleanor A. Blakely, PhD

Report of Task Group on the Implications of the Implementation of the ICRP Recommendations for a Revised Dose Limit to the Lens of the Eye

Summary
This report was commissioned by the IRPA President to provide an assessment of the impact on members of IRPA Associate Societies of the introduction of ICRP recommendations for a reduced dose limit for the lens of the eye.

The report summarises current practice and considers possible changes that may be required. Recommendations for further collaboration, clarification and changes to working practices are suggested.

May 2013
“In regards to thresholds, there is not currently enough available information to make any new specific conclusion with regard to chronic exposure threshold for cataracts”
How did we derive the guidelines for lens exposure limits?
1897: Chalupecky reports cataract in x-rayed rabbits

Chalupecky, H., "Ober die Wirkung der Rontgenstrahlen auf das Auge und die Haut. Centralbl. Augenheilk. 21, 234, 267, 368, 1897.
Early Radiation Cataract Studies

"Ophthalmological survey of atomic bomb survivors in Japan in 1949"

• Few subjects with low doses
• Short follow-up
• Less sensitive techniques

"Cyclotron-induced radiation cataracts" *Science* **110**, 1949

• Chalupecky, 1897
• Rohrschneider, 1932
• Hiroshima, Nagasaki, 1945
• Cyclotron, 1940’s
• Poppe, Cogan, 1950’s
• Merriam & Focht, 1957, 1962
• Merriam & Worgul, 1976
More recent studies are consistent with a much lower threshold model for radiation cataract.
A-bomb survivors

Chernobyl “Liquidators”

Infants treated for facial hemangiomas

Residents of contaminated buildings

Radiological technologists

Interventional medicine workers

Astronauts
Core Curriculum

A Summary of Recommendations for Occupational Radiation Protection in Interventional Cardiology

Ariel Durán,1 MD, FACC, Sim Kui Hian,2 MBBS, FRACP, Donald L. Miller,3 MD, John Le Heron,4 MD, BS, FACR, Renato Padovani,1,5 PhD, and Eliseo Vano,1,5 PhD

REVIEW ARTICLE

Radiation protection of the eye lens in medical workers—basis and impact of the ICRP recommendations

1,2Stephen GR Barnard, BSc, 3Elizabeth A Ainsbury, PhD, 2Roy A Quinlan, PhD and 3Simon D Bouffler, PhD

1Public Health England, Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot, UK
2Durham University, School of Biological and Biomedical Sciences, Durham, UK

PRINCIPLES FOR THE DESIGN AND CALIBRATION OF RADIATION PROTECTION DOSEMETERS FOR OPERATIONAL AND PROTECTION QUANTITIES FOR EYE LENS DOSIMETRY

J. M. Bondy1*, G. Guidlin4, J. Duques4 and F. Martini2

1CEN-NEA, Bas-Atom, SNRE, F-76530 Fontenelle, France
2CEN-NEA-BAS-IRP Radiation Protection Institute, Via del Colli 16, 40136 Bologna (BO), Italy

RADIATION AND CATARACT

Maden M. Rehani1,*, Eliseo Vano2, Olivera Giraj-Bjelac3 and Norman J. Kleiman4

1International Atomic Energy Agency, Vienna, Austria
2Radiology Department, Complutense University, Madrid, Spain
3Vinca Institute of Nuclear Sciences, Belgrade, Serbia
4Mailman School of Public Health, Columbia University, New York, NY, USA
The accessibility of the lens to non-invasive measurement facilitates investigation designed to examine environmental, mechanistic and genetic influences on radiation cataract development.
Ionizing radiation induced cataracts: Recent biological and mechanistic developments and perspectives for future research

Elizabeth A. Ainsbury, Stephen Barnard, Scott Bright, Claudia Dalke, Miguel Jarrin, Sarah Kunze, Rick Tanner, Joseph R. Dynlacht, Roy A. Quinlan, Jochen Graw, Munira Kadhim, Nobuyuki Hamada

ARTICLE INFO

Article history:
Received 24 May 2016
Received in revised form 27 July 2016
Accepted 28 July 2016
Available online 29 July 2016

Keywords:
IR
Radiation cataract
Radiation lens effects
Lens biology

ABSTRACT

The lens of the eye has long been considered as a radiosensitive tissue, but recent research has suggested that the radiosensitivity is even greater than previously thought. The 2012 recommendation of the International Commission on Radiological Protection (ICRP) to substantially reduce the annual occupational equivalent dose limit for the ocular lens has now been adopted in the European Union and is under consideration around the rest of the world. However, ICRP clearly states that the recommendations are chiefly based on epidemiological evidence because there are a very small number of studies that provide explicit biological, mechanistic evidence at doses <2 Gy. This paper aims to present a review of recently published information on the biological and mechanistic aspects of cataracts induced by exposure to ionizing radiation (IR). The data were compiled by assessing the pertinent
Why the lens?

Why radiation cataract?
The lens is one of the most radiosensitive of all tissues

Br J Ophthalmol 1997; 81:257-9
Ionizing radiation exposures that produce minimally detectable and/or clinically relevant eye effects

<table>
<thead>
<tr>
<th>TISSUE</th>
<th>MINIMALLY DETECTABLE CHANGES</th>
<th>VISUALLY DEBILITATING CHANGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lids</td>
<td>6</td>
<td>40</td>
</tr>
<tr>
<td>Conjunctiva</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td>Cornea</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Sclera</td>
<td>15</td>
<td>200</td>
</tr>
<tr>
<td>Iris</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Lens</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Retina</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

_NCRP Report No. 130, 1999; ICRP Pub 118, 2012_
CATARACT

A change in transparency of the lens
Cataract and World Blindness

- 25 million blind people globally due to cataract
- 119 million individuals visually impaired by lens opacification
- Cataract is still the leading cause of blindness in the 3rd world
- Lens opacities can be found in 96% of all individuals older than 60 yrs
- With an increasingly healthy, aging population, the societal and economic burden of cataract surgery is expected to greatly increase
  - Cataract surgery represents 12% of the U.S. Medicare budget and 60% of all Medicare visual costs

WHO, 2002, Eye Diseases Research Prevalance Group, 2004
RADIATION CATARACT

a specific subset of lens opacities
A lens opacity most often originating at our near the visual axis, first appearing in the posterior subcapsular region of the lens.
Why do we care?

- Health impacts on workers
- May be preventable
- Canary in a coal mine?
- Model for low-dose exposure
Radiation cataract provides a way to study potential human health risks following occupational low-dose ionizing radiation exposures.
Potential visual disability and morbidity resulting from radiation cataract and/or its treatment is greatly underappreciated.
The lens
Major Cataract Subtypes

- Cortical
- Nuclear
- Posterior SubCapsular (psc)
- Mixed
Posterior SubCapsular (PSC)
Radiation Cataract Pathomechanism

*Genotoxic damage to the lens epithelium*

- Lens shielding studies
- Mitotic inhibition studies
- Irradiation of posterior 2/3 lens
IONIZING RADIATION

Damage to Lens Epithelial DNA

[ dividing cells ] → [ differentiating cells]

Abnormal Lens Fibers

Loss of Transparency

CATARACT
Measuring Lens Damage

- Biomicroscopy (slit lamp)
- Retroillumination
- Scheimpflug Imaging
- Contrast Sensitivity
Nikon FS-3 Photo-Zoom Slit Lamp
Nidek EAS-1000 Scheimpflug Camera
Radiation Induced Posterior Subcapsular Opacity

Retroillumination

Slit Lamp Exam

Interventional cardiologist
with 22 years experience
Quantifying radiation-induced lens changes “cataract staging”

Merriam-Focht scoring
LOCS II
LOCS III
Focal Lens Defects
Digital Scheimpflug
Contrast Sensitivity Testing
Slit Lamp Imaging of Radiation Cataract Grades

Merriam-Focht Scoring

Cataract Classifications

- Anterior 1+
- Posterior 2+
- Anterior 3+
- Posterior 4+
Scheimpflug Imaging of Radiation Cataract

Quantitative analysis of lens changes
Holladay Automated Contrast Testing

- Rotationally symmetric targets
- Randomly presented optotypes
- Test time < 5 min/eye
- Testing at 1.5, 3, 6, 12, 18 cycles/degree
- 1-100% contrast under mesopic or photopic luminence
Contrast Sensitivity Testing in Interventional Cardiology

IC subject A
(abberrent)
M-F 1.5

IC subject B
(normal)
M-F 0.0
How can we reduce or eliminate radiation exposure risks to the eye?
Eye Protection!!

Weight: 80 g
Equivalent to 0.75mm of lead
Front and lateral protection is essential
Effect of leaded eyewear and additional shielding

Table 1

<table>
<thead>
<tr>
<th>Shielding Strategy</th>
<th>Low-dose PA Fluoroscopy</th>
<th>PA DSA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lens Dose Rate</td>
<td>Lens Dose Reduction Factor</td>
</tr>
<tr>
<td>Image intensifier at 20 cm</td>
<td>1.18 mSv/h</td>
<td>135 mR/h</td>
</tr>
<tr>
<td>Image intensifier at 3 cm (close)</td>
<td>0.54 mSv/h</td>
<td>62 mR/h</td>
</tr>
<tr>
<td>Plus leaded table skirt</td>
<td>0.492 mSv/h</td>
<td>56.2 mR/h</td>
</tr>
<tr>
<td>Plus unleaded eyeglasses</td>
<td>0.489 mSv/h</td>
<td>55.8 mR/h</td>
</tr>
<tr>
<td>Plus leaded eyeglasses</td>
<td>0.052 mSv/h</td>
<td>5.9 mR/h</td>
</tr>
<tr>
<td>Plus scatter-shielding drape</td>
<td>0.041 mSv/h</td>
<td>4.7 mR/h</td>
</tr>
<tr>
<td>Plus leaded eyeglasses and scatter-shielding drape</td>
<td>LLD</td>
<td>LLD</td>
</tr>
<tr>
<td>Plus ceiling-suspended shield</td>
<td>LLD</td>
<td>LLD</td>
</tr>
<tr>
<td>Plus ceiling-suspended shield and scatter-shielding drape</td>
<td>LLD</td>
<td>LLD</td>
</tr>
<tr>
<td>Plus rolling shield</td>
<td>LLD</td>
<td>LLD</td>
</tr>
</tbody>
</table>

Note.—LLD = below the lower limit of detection (0.001 mSv/h); RM = reference measurement.

25X increased protection

The treatment for cataract is surgical removal

- There are no therapeutic interventions to slow or reverse cataract formation
- Cataract surgery has a “success rate” of >90% (defined as an improvement in vision)

Nevertheless.....
Potential visual disability and morbidity resulting from radiation cataract and/or its treatment is greatly underappreciated.
Potential surgical/post-surgical complications of cataract extraction

- Endophthalmitis
- Uveitis
- Hyphema
- Corneal edema
- Choroidal hemorrhage
- Cystoid macular edema
- Lens dislocation
- Rupture of the posterior capsule
- Retinal detachment
- Glaucoma
- Posterior subcapsular opacification
- Pain and discomfort
Potential post-operative visual complications of cataract surgery

- Glare and flare
- Decreased acuity
- Decreased contrast sensitivity
- Photophobia
- Stereopsis
Cataract surgery risk estimates

- Posterior Sub-Capsular Opacification
  - 10%
- Cystoid Macular Edema
  - 1-10%
- Retinal Detachment
  - 0.5%
- Permanent Vision Loss
  - 0.1%
- Death
  - 0.01%
Issue 2: Occupational Dose Limit for the Lens of the Eye

Q2–2: How should the impact of a radiation-induced cataract be viewed in comparison with other potential radiation effects?

Response: The Society wishes to bring the following information to the attention of the Commission:

“...available data suggests mortality following cataract surgery is on the order of 0.1% and that morbidity, defined both from an ophthalmological as well as medical standpoint, is consider-ably higher. Of equal import, prior to a documented clinical need for cataract surgery, there may be accompanying progressive decreases in visual acuity, contrast sensitivity and visual function that may negatively impact worker performance”

“In conclusion, the combined morbidity and mortality risks of surgical correction of radiation-induced cataracts (1% or more) and the, as yet unquantified, risk of a physician misdiagnosing or mistreating a patient because of loss of visual acuity due to the presence of an undiagnosed cataract, greatly outweighs the risk of cancer in affected individuals. “
Continued follow-up of various occupationally exposed human cohorts as well as additional experimental animal studies will likely help further refine the radiation cataract “threshold”, inform appropriate ocular risk guidelines, and lead to a better understanding of fundamental mechanistic principles underlying adverse ocular health outcomes in exposed populations.
Special Thanks

Columbia University Center for Radiological Research
  David Brenner, PhD
  Eric Hall, PhD, DSci
Colorado State University
  Mike Weil, PhD
National Council on Radiation Protection (NCRP)
  Committee 2-3: Radiation Safety Issues for Image-Guided Interventional Medical Procedures; Steve Balter, PhD
International Commission on Radiological Protection (ICRP)
  Symposium Organizing Committee, Julian Preston, PhD
  Committee 1; Tissue reactions and other non-cancer effects of radiation; Fiona Stewart, PhD
IAEA
  RELID: Madan Rehani, PhD, Eliseo Vano, PhD
U.S. Department of Energy (DOE)
  Low-dose Radiation Research program
NASA
  Space Radiation Health Program
Basil V. Worgul, Ph.D., 1947-2006
Professor of Radiation Biology
Departments of Ophthalmology and Radiology
Columbia University