EPRI Perspectives on NCRP Commentary 26: Guidance on Radiation Dose Limits for the Lens of the Eye

Nuclear Sector, Radiation Safety Program

Purpose

This Technical Issue Summary is intended to provide a brief background on the issue of radiation dose to the Lens of the Eye, the key findings of the National Council on Radiation Protection and Measurements (NCRP) Commentary on the issue, and EPRI perspectives on implications for consideration in nuclear power plants.

Introduction

The response of the clear crystalline lens of the eye to ionizing radiation induced damage is the loss of lens clarity. This results in clouding or opacification known as a cataract that in extreme cases, usually after high absorbed doses > 5 Gy (500 Rad) in a single exposure can cause blindness (i.e., significant visual impairment). However, exposure of the lens to low doses of radiation can also lead to opacification many years later. Recent epidemiological evidence has suggested that the threshold dose of ionizing radiation for specific tissue reactions with late manifestation (including the lens) may be lower than previously thought.

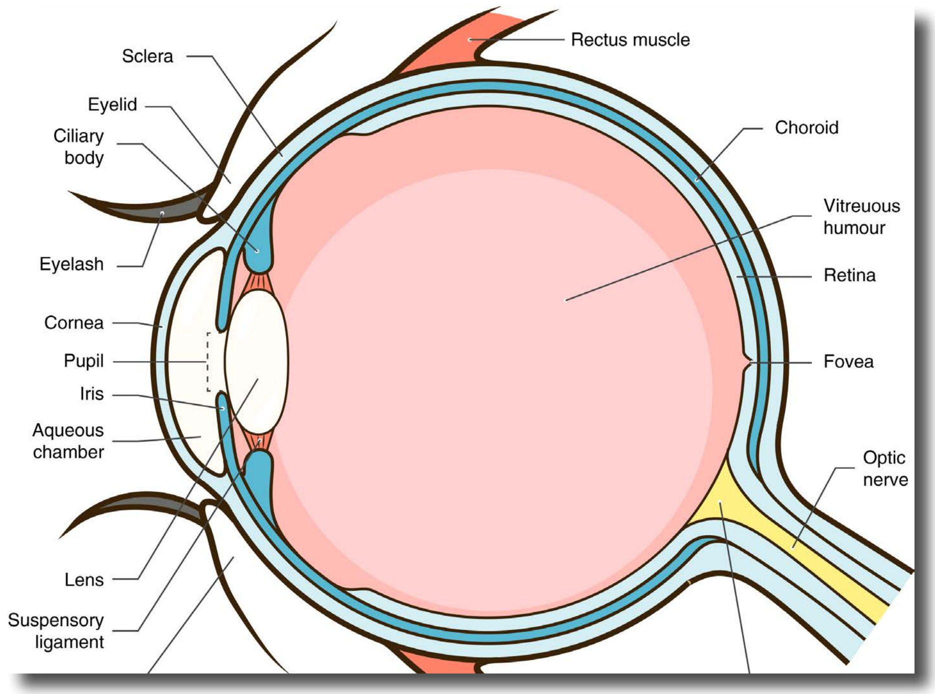

Figure 1. Diagram of the human eye

In 2012, the International Commission on Radiological Protection (ICRP) reviewed tissue reactions and threshold doses, and evaluated the available epidemiological evidence of cataracts in radiation-exposed human populations. The resulting ICRP Publication 118 (ICRP 2012) suggested a reduced threshold for lens of eye effects (cataracts and other opacities) of 0.5 Gy (50 Rad) for low-LET radiation for acute or protracted exposures. Earlier assumed dose threshold values for vision-impairing cataracts were much higher at about 2 to >5 Sv (200 to >500 Rem) for single acute exposures and > 8 Sv (800 Rem) for protracted exposures. Because of the lowered nominal thresholds for lens eye effects, the ICRP recommended a reduction of the equivalent dose annual limit for occupational exposure of the lens of the eye to 20 mSv (2 Rem), averaged over 5 y, with no single year greater than 50 mSv (5 Rem). The International Atomic Energy Agency and the European Commission have adopted the new recommendation into their Basic Safety Standards as a dose limit.

At the request of the Nuclear Regulatory Commission, the NCRP convened Scientific Committee 1-23 to further examine the issue of recommendations for the lens of the eye. SC 1-23 was charged with preparing a commentary evaluating recent studies on the radiation dose response for the development of cataracts; considering the type and severity of the cataracts as well as the dose rate. The resulting report, NCRP Commentary 26 (NCRP 2016), was published at the end of 2016, and provides background and a recommendation on whether existing dose limits to the lens of the eye should be changed. NCRP Commentary No. 26 reviewed the most current information pertaining to epidemiologic and mechanistic understanding of the development of cataracts and determined that the association between exposure to radiation and initiation or development of certain cataracts is possible at lower does than previously considered. NCRP's evaluation of the available epidemiology was informed by a review of scientific information by EPRI (EPRI 2014).

NCRP Findings in Brief

NCRP determined it was not possible to quantify a specific threshold value for either acute or chronic exposures to the eye lens due to uncertainties that are still under scientific review. Notwithstanding the uncertainties, NCRP concluded that much of the evidence suggests the possibility that effects (e.g., lens opacities and/or cataracts) could occur at lower doses than previously considered. NCRP determined that it was prudent to reduce the current recommended annual lens of the eye occupational dose limit from an equivalent dose of 150 mSv (NCRP, 1993) to an absorbed dose of 50 mGy. NCRP also emphasized the importance of application of the ALARA principal to lens of eye exposures.

The NCRP addressed four core questions, which are listed below with summary responses. Readers are encouraged to review the document for the full NCRP perspective on these important considerations and their recommendations for additional epidemiological and radiation biology research.

1. Should radiation-induced cataracts be characterized as stochastic effects or tissue reactions?

   There is insufficient evidence to change our understanding of underlying effects. NCRP has determined that the tissue reaction (threshold type) model should continue to be used for radiation protection purposes at this time.

2. What effects do linear-energy-transfer (LET), dose rate, acute and/or protracted dose delivery have on radiation cataract induction and progression?

   NCRP has determined that further, high-quality epidemiological and mechanistic studies are required before the question of how exposure to ionizing radiation contributes to further loss of lens clarity can be fully answered.

3. How should detriment be measured and/or evaluated for radiation cataracts?

   NCRP recognizes that, while the mechanisms underlying the transition of minor lens opacifications to clinically significant vision-impairing cataracts are still not well understood, it is prudent to regard eye exposures and the potential for lens tissue effects in much the same way as whole-body exposures. NCRP emphasizes ensuring lens of eye exposures are consistent with ALARA principles.

4. Based on current evidence, should NCRP change the recommended annual occupational equivalent dose limit for the lens of the eye?

   NCRP recommends that the annual dose limit for occupational exposures for the lens of the eye be reduced to 50 mGy (5 Rad). A systematic review of the current eye epidemiology data has shown that the probable risks for cataracts are likely increased at an exposure level that is less than the earlier estimates by ICRP and NCRP. NCRP acknowledges that most of the available data on lens effects have large associated uncertainties and limitations that do not yet support a quantitative estimate of a specific threshold value for effects from either acute or protracted lens exposures.

EPRI Perspectives

The ICRP recommendations from 2012, and now the NCRP recommendations, are a major shift in the recommended levels for protection of lens of the eye, and have significant implications for all users of radiation and radioactive material. In the United States, additional attention is warranted, although changes to regulations are not yet being considered. Outside the United States the recommendations have been, or are being, translated into regulations, and most nuclear power plants will need to comply with new requirements in the near future. The implications for nuclear power plant radiation protection programs will generally fall into four broad categories: field condition reviews (e.g. assessment of field gradients), personnel dosimetry and radiation field surveys, personnel protective equipment and worker training. EPRI is currently developing guidance to support implementation of sound radiation protection programs in this area. The following discussion is broadly applicable to all nuclear power plants, wherever they may be located.

The revised NCRP recommendation means that the recommended dose limit for the lens of the eye is numerically the same as the Effective Dose limit. The same is true for the ICRP's recommendations. Thus, there is no longer a difference between the two, and it can no longer be assumed that the Effective Dose will be the more limiting criteria. The primary impact on nuclear power facilities is that, for some work conditions, the lens of eye dose may become a more limiting condition, as opposed to the current situation where eye dose is rarely the most restrictive criteria. Radiation protection programs will need to consider assessing the procedural implications relative to dose gradient surveys and assessments, review existing lens of eye dosimetry algorithms and dose recording practices, assess the appropriateness of any protective equipment for the lens of eye, and implement additional worker training.

Evaluation of Field Conditions

While the majority of the occupational dose to the lens of the eye in nuclear facilities is the result of time spent in uniform-radiation fields, there are certain work tasks and radiation field conditions (i.e. dose rate gradients) where non-uniform radiation field conditions exist. These may include fields with lower penetrating sources, such as low-energy gamma and higher-energy beta ionizing radiation, and work locations where the source is exposing the eyes to a greater extent than the rest of the body. An early action for programmatic review should include assessment of radiation field and work conditions where lens dose could be close to or exceed the whole body effective dose. Consequently, the field conditions where lens dose rate exceeds effective whole body dose rate will become important. There are field conditions that could result in a lens dose that exceeds effective whole body effective dose equivalent:

- Work tasks where dose gradients result in eye doses higher than whole body dose, in particular work with overhead source terms or in areas where the whole body is shielded more than the head such as work near steam generator manways for example.

- Consideration of special conditions, such as potential operation with failed fuel (radionuclide energy mix changes) or extended work in a PWR containment at power or steam affected zone entries at a BWR. Under these conditions higher energy betas from noble gases and secondary electrons from high energy gamma may need to be assessed relative to protection of the eye lens.

Operational and outage radionuclide mix reviews (radiation field characterization) will also be warranted. Radiation field energies where beta dose rates may be significant enough to warrant personal protection for the lens will also be more important to understand if lens and whole body exposures are different.

With respect to beta radiation; energies greater than ~0.7 MeV have the capability to reach the lens of the eye through the depth of 300 mg/cm^2 (also referred to as Hp(3), dose equivalent at 3 mm depth). High energy gamma radiation (about 1.2 MeV and higher) has the potential to cause air scattered electrons due to Compton scattering of sufficient energy to reach the lens of the eye (range of >300 mg/cm^2). Cobalt-60 Sr/Y-90, and some noble gas and fission products have energies that can penetrate beyond 300 mg/cm^2 tissue depth. Beyond review of waste streams, irradiated component work, and reactor coolant contaminants, plants should also review potential changing radiological conditions possible from fuel leakage or infrequent entries to steam affected areas at BWRs or PWR power entries to identify additional review triggers and/or procedure changes.

Proactive evaluation of existing procedures and potentially affected work tasks and/or worker groups will help determine what population of workers may be expected to receive significant doses to the lens of the eye. While this population is expected to be limited, up front evaluation will ensure protection implications are identified and proper monitoring protocols defined in advance. With smaller margins to the regulatory limits, prudence dictates a careful assessment of decision criteria for when dosimetry relocation should be considered or provided as an additional dosimeter close to the eye. Survey documentation requirements for area monitoring relative to lens of the eye and administrative dose limits at each facility also will need to be evaluated and changed as necessary to ensure proper monitoring decisions are made.

Fundamentally, these evaluations will be folded as necessary into existing plant procedures that implement methods such as engineered controls, personal protective equipment, administrative controls, and other ALARA techniques that optimize the radiation dose to the lens of the eye and whole body effective dose.

Monitoring and Dosimetry

Dosimetry monitoring of lens of eye dose, as well as assessing field conditions with existing instrumentation, will be impacted by a lower lens of eye dose limit. Procedure guidance for making lens of the eye monitoring decisions, in particular for workers exposed to non-uniform radiation fields in the course of their work, relies on adequate assessment of area dose rates. Personnel dosimeter energy responses must also be calibrated to the expected field energies for the work areas. With less margin between the lens and effective dose limits, it will be important to reassess dosimeter algorithms and survey meter correction factors for example to ensure over or under reporting is not an issue.

Adequate and conservative dosimetry utilizing algorithms or stay-time assessments are normally based on tissue depths and associated correction factors for the skin and deep tissue, not typically for the 3 mm eye lens tissue depth. Most nuclear facilities do not currently estimate lens dose prior to entry to perform work since the differences between lens dose and effective dose almost always assured lens doses well below existing limits. The lower recommended value (already implemented as a limit outside the United States) would increase the importance of ensuring that not only accurate but also not overly conservative assessments of lens of eye doses are performed.

EPRI has a guidance document currently under development, "Lens of Eye Dose Guidance and Good Practices," that reviews current multi-element dosimeter use among other aspects of the potential dose limit change. Practitioners are reminded that personnel dosimetry has been designed primarily for determining shallow dose at Hp(0.07) and deep

Figure 2. Evaluation of field conditions is important for proper characterization of dose to the lens of the eye

dose at Hp(10). Lens of eye dose operational quantities have not been well defined concerning which dose conversion factors to use for photons and electrons. The personnel dosimeters that have the ability to monitor at Hp(3) typically have multiple elements in a moderate to large size badge, and that badge is not normally placed near the eyes. Current multi-element design dosimeters will remain useful in most power plant applications except those where the larger size of the dosimeter could interfere with head placement for a particular job task. For situations where a larger multi-element dosimeter is not a good fit, consideration of the need for and use of new (not presently widely available) 3 mm tissue equivalent dosimeters will be an option once appropriate calibration and energy standards are defined.

In the U.S., the National Voluntary Laboratory Accreditation Program (NVLAP) does not yet have a requirement or test protocol for lens dose. EPRI has initiated research to examine the dosimetry issues in more detail, to help to inform consensus standards and possible future accreditation categories. Ensuring an understanding of the response of your facility's existing dosimeters relative to monitoring at Hp(3) will be necessary to ensure accuracy in reporting. Lens of eye monitoring with multi-element badges involves measurement of radiation dose at a tissue equivalent depth of 3mm Hp(3) or H(3) can be estimated with appropriate algorithms corrected for energy as necessary using skin and deep dose measurement techniques (i.e. at Hp(0.07) and Hp(10)). Dosimeter algorithm reviews will be necessary to determine if changes are warranted to improve/validate accuracy should the eye lens limit be lowered.

For doses that are primarily from above the head, where the head is more highly exposed than the trunk, there are implications for the use of the weighting methods used to calculate effective dose for external exposures in light of a reduced LDE limit. In certain situations, particularly those with a dose gradient above the head, the lens dose could be limiting where under present limits this is not a concern. For calculations of effective dose performed using multiple dosimeters, procedural guidance will be necessary to ensure that the worker's remaining dose margin is calculated based on the most restrictive dose limit.

Instruments capable of being calibrated and used for assessment of lens of eye dose rates will be important tools to aid in conducting assessments of field conditions when considering dosimeter placement in particular. Field survey instrumentation correction factors for monitoring at the 3mm (300mg/cm^2) depth will also be warranted. The current practice of conservatively using "open window type" ion chamber assessments to assess potential eye lens doses for beta fields will likely be too conservative for continued practical use with a lower eye dose limit. Updated studies to determine correction factors that can be applied at the 300mg/cm^2 depth similar to the practice for ion chambers to conduct skin dose rate surveys will be warranted. While under development, there are presently no peer reviewed standard dosimetry quantities or conversion factors for lens dose equivalent. While survey instrumentation with wall chamber thickness of 300 mg/cm^2 are currently commercially available, calibration procedures will need to be developed that are appropriate for the radionuclide mix predominant for the field conditions at a given facility. Standards organizations (IEC and ISO) are formulating revisions to existing guidance to provide dose conversion factors for H(3) lens equivalent calibration use.

Protection of the Lens

For the nuclear power industry, there are two primary methods for protecting the lens of the eye from high radiation dose. The first method is through application of ALARA principles to gamma radiation dose to the head and eyes and as necessary reducing the non-penetrating radiation dose to the lens via eye protection for higher energy beta (above about 0.7 MeV). Low energy photons are also a consideration for the medical industry but not typically of importance to power plants.

Personnel protective equipment such as safety glasses, face shields, and respirator face pieces can be effective protection in work environments with higher energy beta present. EPRI initiated research on dosimetry will also examine the protection that may be afforded by typical types of personnel protective equipment utilized in the nuclear power plant environment. It is important to include evaluation of the "whole radiation field", since pure beta or even predominantly beta dose rates are not common in the power reactor environment; i.e. the beta dose rates may or may not be an important component of the radiation field even if energies exceed the 0.7 MeV lens of eye thickness.

Most utility radiation protection programs do not require estimation of anticipated lens dose prior to entry because normal protection for whole body and skin will keep the lens dose well below the previously recommended 15 Rem limit. With a lower lens dose limit, procedures will need to recognize that evaluation of the lens dose may be necessary under certain conditions prior to task performance to allow for consideration of PPE (in addition to dosimetry placement) that can be used as part of a dose reduction plan. There is currently no consistent approach to quantify protection factors for typical protective equipment used by workers in a power reactor. EPRI has begun to examine the question of what level of protection is afforded by different types of equipment, and to develop standard methodologies to allow an assessment of the protection that will be accepted as a demonstration of compliance. Subsequent EPRI lens of eye dose guidance and other documents are planned to provide nominal protection factor data for commonly used protective materials (e.g. respirator face shields, bubble suit masks, safety goggles etc.) with companion energy information.

Training and Risk Communication

Properly communicating and contextualizing a lens of the eye limit change and the associated risk discussion will be an important activity for utilities to manage during ongoing radiation worker training. Development of occupational training materials should clearly present the difference in risk endpoints for effective dose equivalent vs. lens absorbed dose or dose equivalent (e.g. treatable eye opacity tissue effects compared to whole-body cancer risks at similar doses). Proper communication about the distinctions between the significant impairment of sight at very high doses, and the possible occurrence at lower doses of lens opacities of little clinical relevance (but that may progress to cataracts), will be important for workers to understand.

References

EPRI 2014, Epidemiology and Mechanistic Effects of Radiation on the Lens of the Eye: Review and Scientific Appraisal of the Literature, Product ID 3002003162, November 2014.

ICRP 2012, ICRP Statement on Tissue Reactions / Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context. ICRP Publication 118. Ann. ICRP 41(1/2).

NCRP 1993, NCRP Report 116, Limitation of Exposure to Ionizing Radiation – Recommendations of the National Council on Radiation Protection and Measurements, March 1993, ISBN 0-929600-30-4

NCRP 2016, Commentary No. 26 - Guidance on Radiation Dose Limits for the Lens of the Eye, December 2016, ISBN 978-0-913392-17-1.

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