Lens of Eye Dose Limit Changes

Current Status of the Potential Regulatory Changes and Possible Effects on Radiation Protection Programs at Nuclear Power Plants

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Technical Update, October 2013

EPRI Project Manager

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ABSTRACT

Recent research suggests that the threshold for cataract formation as a result of exposure to radiation could be lower than previously considered. The International Commission on Radiological Protection (ICRP) is now recommending a dose limit for the lens of the eye of an average of 20 mSv (2 rem) per year, equivalent to their current recommendation for Total Effective Dose Equivalent (TEDE). The Nuclear Regulatory Commission (NRC) is considering reducing the lens of the eye dose limit to 50 mSv/yr (5 rem/yr). Any reduction in lens of eye dose limits will require a reevaluation of monitoring and protection practices.

The Electric Power Research Institute (EPRI) has begun a project to identify the state of the industry in terms of lens of eye dose monitoring and protection. In addition, the project team is reviewing radiation, energy spectra, and situations at power plants that would expose the lens of the eye to greater than the deep dose equivalent (DDE).

This document is a technical update that identifies issues that will need to be addressed if a lower lens of eye dose limit is adopted, including the following:

- Monitoring beta dose rate with survey instruments will become more important.
- Monitoring dose at 300 mg/cm^2 may require further evaluation to ensure results are accurate for the lens of the eye.
- A decrease in lens of eye dose limit may have a significant effect on the use of Effective Dose Equivalent.
- Worker protection methods (e.g., use of face shields or goggles) may require reevaluation.

Keywords
Beta radiation
Effective Dose Equivalent
Lens of Eye
Radiation Dose
Radiation Dose Limit

CONTENTS

1 INTRODUCTION

The purpose of this technical update is to provide early information on what aspects of power plant radiation protection programs may need to change if the lens of eye dose limits are reduced. The assumption for this report is that the dose limits for the lens of the eye will be reduced to a value the same as the whole body dose. That is, Effective Dose Equivalent (ICRP-26) or Effective Dose (ICRP-60 or ICRP-103).

The reasoning for ICRP's decision to reduce the recommended limit for the lens of the eye is described in ICRP-118. EPRI is planning to review the ICRP-118 reasoning as part of a separate project and it will not be discussed in this technical update report.

While it is recognized that potential changes to the lens dose limit may have a significant effect on the radiation protection programs for other licensees such as medical and uranium facilities, this technical update report will address primarily the power reactor issues.

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BACKGROUND INFORMATION

ICRP Background Information Relating to Lens of Eye Dose Limit

Tissue Effects Statement

The ICRP issued a "Statement on Tissue Reactions" in April of 2011, and followed with ICRP Publication 118, "ICRP Statement on Tissue Reactions and Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context" in 2012. The key issues addressed in ICRP-118 were the following:

- The threshold for lens of eye effects (cataracts and opacities) is now considered to be 0.5 gray (50 rad). Previous dose limits were based on a much higher threshold, in the range of 5 gray (500 rad).
- The reasoning for this reduction in the threshold is that additional data was evaluated that considered more individuals at a lower exposure level and they were followed for a longer period of time. The resulting data indicated that the earlier studies did not adequately consider the longer latent period for lower eye dose exposures. Table 2-1 is from ICRP-118 and summarizes some recent studies where the threshold dose for lens cataracts was specifically evaluated. The results indicate thresholds of 0.34 to 0.7 gray (34 to 70 rad).
- A reduced occupational exposure for the lens of eye is recommended to be 20 mSv/yr (2.0 rem/yr), averaged over 5 years, and no single year > 50 mSv (5 rem). This is the same value as the ICRP recommendation for effective dose limit, which is applicable to the whole body.
- Other information concerning circulatory disease was also discussed, such as a reduced threshold for the heart and brain; however, those recommendations will not be discussed in this technical update report.

It should be noted that the ICRP and the U.S. National Council on Radiation Protection & Measurements (NCRP) radiation protection philosophies differ slightly. The NCRP states that the objectives of radiation protection are to prevent the occurrence of clinically significant radiation induced *deterministic effects* by adhering to dose limits that are below the apparent threshold levels and to limit the risk of *stochastic effects*, cancer and *genetic effects* to a reasonable level in relation to societal needs, values, benefits gained and economic factors (NCRP-116, 1993). The ICRP aim is to contribute an appropriate level of protection against the *detrimental effects* of radiation exposure without unduly limiting desirable human actions associated with such exposure (ICRP-103). For the ICRP, detriment is the total harm to health as a result of exposure to a radiation source, and tissue reactions are those detriments arising from non-cancer effects of radiation on health.

Table 2-1
Adapted from ICRP-118 Table 4-3 Describing Recent Studies for Lens Cataract Thresholds

Study	Cataract type	Threshold dose	Confidence intervals	Reference
Atomic bomb survivors (acute exposure)	Cortical cataract Posterior subcapsular opacity	0.6 Sv 0.7 Sv	90%: <0-1.2 Sv 90%: <0-2.8 Sv	Nakashima et al. (2006)
Atomic bomb survivors (acute exposure)	Postoperative cataract	0.1 Gy	95%: <0-0.8 Gy	Neriishi et al. (2007)
Chernobyl clean-up workers (fractionated protracted exposure)	Stage 1-5 cataract Stage 1 cataract Stage 1 non-nuclear cataract Stage 1 superficial cortical cataract Stage 1 posterior subcapsular cataract	0.50 Gy 0.34 Gy 0.50 Gy 0.34 Gy 0.35 Gy	95%: 0.17-0.65 Gy 95%: 0.19-0.68 Gy 95%: 0.17-0.69 Gy 95%: 0.18-0.51 Gy 95%: 0.19-0.66 Gy	Worgul et al. (2007)

U.S. Nuclear Regulatory Commission

Existing NRC Regulations

Current NRC regulations are based on ICRP-26 and have a Lens Dose Equivalent (LDE) limit of 150 mSv (15 rem) per year, measured at a depth of 300 mg/cm^2. The original annual limit for LDE specified in ICRP-26 was 300 mSv, but the ICRP recommended in its statement from its 1980 meeting that the limit be reduced to 150 mSv. The whole body (effective dose equivalent, EDE) limit is 50 mSv (5 rem) per year with no averaging of dose over multiple years. Therefore, there is a difference of a factor of 3 when comparing the LDE to EDE. The NRC requires reporting of radiation dose on NRC Form 5, and this information is summarized in NUREG-0713 "Occupational Radiation Exposure at Commercial Nuclear Power Reactors…", published annually. The doses for shallow dose (skin at 0.07 mm), lens of eye (3 mm), and deep dose (10 mm) are listed on the NRC Form 5.

Potential Changes to NRC Regulations

In 2011, the NRC requested public comment (NRC-2009-0279) on possible lens dose limit changes. The NRC considers the effects of this potential regulation change on all radiation users, not only nuclear power plants. Hospitals, uranium manufacturing, and other industries will have different hazards and exposure situations. The NRC had considered 3 options for lens dose limits:

- No change; continue with 150 mSv/yr (15 rem/yr)
- Adopt ICRP recommendation; 20 mSv/yr average (2 rem/yr), and no single year > 50 mSv (5 rem).
- Adopt a single, reduced limit, such as 50 mSv (5 rem) per year or 20 mSv (2 rem) per year.

After receipt of comments and recommendations to the NRC commissioners, the NRC commissioners decided (SRM-12-7-12) that discussions should continue with the stakeholders on lens of eye dose limits. That is, no change to limits as yet. The NRC commissioners, in the same SRM-12-7-12 document, decided not to reduce the EDE limit below its existing 50 mSv (5 rem) per year. However, the lens dose limit could be reduced to 50 mSv/yr (5 rem/yr) (Cool, 2013).

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INTERNATIONAL CONSIDERATIONS FOR LENS OF EYE DOSE

History of International Recommendations on Lens Dose

International recommendations for the lens of the eye have changed over the years, and the following are some of the significant benchmarks:

- ICRP-26, Recommendations of the ICRP (1977) – 300 mSv/yr (30 rem) for lens of eye
- ICRP Statement and Recommendations of the International Commission on Radiological Protection from its 1980 meeting – recommended dose-equivalent limit be reduced from 300 mSv to 150 mSv
- ICRP-60, Recommendations of the ICRP (1990) – 150 mSv/yr (15 rem) for lens of eye
- ICRP-103, Recommendations of the ICRP (2007) – 150 mSv/yr (15 rem) for lens of eye
- ICRP-118 and Statement of Tissue Reactions (2011/2012) – lens dose 20 mSv/yr (2 rem) averaged over 5 years, with any one year maximum at 50 mSv (5 rem)
- IAEA Safety Standard, Radiation Protection and Safety of Radiation sources: International Basis Safety Standards, General Safety Requirements, Part 3- interim (2011): lens dose 20 mSv/yr (2 rem) averaged over 5 years, with any one year maximum at 50 mSv (5 rem)
- European Commission Proposal for a Council Directive Laying down Basic Safety Standards for Protection against the Dangers arising from Exposure to Ionising Radiation (2012); lens dose 20 mSv/yr (2 rem).

In summary, the international recommendations have changed and draft regulations have changed to reduce the lens dose limit. Those countries that are committed to IAEA safety standards will be subject to the new limit, although some implementation time may be permitted. As stated in the previous section, the U.S. is considering lowering the lens dose limit, possibly to 50 mSv (5 rem) per year.

Information on Current Status of Selected Countries for Lens Dose

Canada presently maintains the 150 mSv (15 rem) per year lens dose limit, and utilities do not maintain an administrative dose limit below that level. They do not measure lens dose directly, but control the lens dose by assuring that the skin dose is sufficiently low. The Canadian Nuclear Safety Commission has issued a discussion paper DIS-13-01 in August, 2013, "Proposals to Amend the Radiation Protection Regulations." In this document, there is a recommendation to change the limit for the lens of the eye to agree with the ICRP recommendation, 50 mSv in any one year and a total of 100 mSv over 5 years (i.e., average 20 mSv per year).

France presently maintains the 150 mSv (15 rem) per year lens limit. EDF is not currently required to report lens dose; however, they are working with the dosimetry vendor to utilize an improved dosimeter for lens dose. EDF has evaluated plant situations where lens dose could be limiting based on the comparison to head dose (lens) and body dose (chest badge). With the current dose limits, a ratio of 7.5 (150 mSv/20 mSv) is necessary for the lens to be limiting. That is, if the head dose rate is 7.5 times the chest/whole body dose rate, then the lens dose may reach the limit before the whole body dose. If the lens dose limit is reduced, then this ratio would decrease to 1.0 (same limit for lens and whole body). Preliminary evaluations show that certain tasks, such as pressurizer heater work with the dose from overhead, could result in dose gradients that would make the lens dose limiting.

In Spain, utilities are not currently required to report dose to the lens of the eye, and they do not maintain an administrative dose limit below the regulatory limit of 150 mSv (15 rem) per year.

In Brazil, the lens of eye dose limit is the same as the whole body limit, 20 mSv (2 rem) per year, averaged over 5 years, with no single year exceeding 50 mSv (5 rem) per year. Administrative limits for the lens are 20 mSv (2 rem) per year, and not more than 75 mSv (7.5 rem) per 5 year period.

In Sweden, utilities are not currently required to report dose to the lens of the eye, and they do not maintain an administrative dose limit below the regulatory limit of 150 mSv (15 rem) per year.

In South Korea, utilities are not currently required to report dose to the lens of the eye, and they do not maintain an administrative dose limit below the regulatory limit of 150 mSv (15 rem) per year. The utility has an algorithm for determining lens of eye dose, but it has not been finalized because there is no current requirement for reporting.

Summary of Selected Technical Information

A number of technical issues related to lens dose have been reported in journals and at technical meetings. The list below is by no means a complete list, but it provides information relating to the range of issues being evaluated related to lens of eye dose.

Regulatory Limits

M.C. Thorne, J. Radiol. Prot. 32 (2012), 147-154. This paper suggests that it is illogical to have a lens dose at the same level as the whole body and suggests that one solution is to assign a tissue weighting factor to the lens and include the lens in an effective dose calculation.

Lens Dosimetry

The International Commission on Radiological Units (ICRU) previously defined an operational quantity $H_p(3)$ as a useful lens dose equivalent measurement tool (ICRU Report 57). ICRP Report 116 more specifically defines organ dose (i.e. equivalent dose) to the whole lens itself H_{lens}. Therefore, evaluations of photon and electron dosimetry comparing operational quantities and measurement techniques against the whole lens organ equivalent dose are needed for typical nuclear power plant radiation fields. Some early attempts at addressing such items include the following example papers. The International Standards Organization have also begun drafting a revised standard on lens, skin, and extremity dosimetry (expected to be completed by 2015).

R. Behrens, J. Radiol. Prot. 32 (2012), 455-464. This paper discusses the operational quantity $H_p(3)$ for lens dosimetry. It determines that both the slab phantom and the cylindrical phantom are reasonably effective in evaluating $H_p(3)$. The paper also reviews the depth of 3mm for the lens. It suggests that the use of 3 mm may be non-conservative for non-penetrating radiations.

R. Behrens, G. Dietze, Phys. Med. Biol. 56 (2011), 425-437. This paper discusses methods of calculation of conversion coefficients for the eye lens, and discusses geometry, photon energies, secondary electrons, and Monte Carlo simulations. Recommended methods for calculation are provided.

Lens Cataract Threshold

These papers are two examples that support the reduction of the threshold for lens cataracts.

Worgul, et al, Radiation Research 167 (2007), 233-243. About 8,600 cleanup workers from Chernobyl were assessed at 12 years and 14 years following exposure, and a threshold for cataract formation was determined to be less than 1 gray (100 rad).

B.S. Jacobsen, Radiation Protection Dosimetry (2005), Vol 1, 113, No. 1, 123-125. Cataracts in retired actinide exposed radiation workers were evaluated. Radiation-induced cataracts were determined to be primarily post-subcapsular (PSC), and a higher incidence of cataracts was found in those with 0.2 – 0.6 gray compared to those exposed to less than 0.2 gray.

Instrumentation

Beta and gamma surveys in nuclear power plants are often taken with Geiger Mueller (GM) detectors and ion chambers. However, when an accurate determination of beta dose rate is required, most often ion chambers are used. Some typical instruments used are the Thermo (Eberline) RO-20 and the Ludlum 9-3. While there are many other manufacturers, these two are typical of survey instruments in normal use. These ion chambers have sliding beta shields that can be moved to expose the ion chamber with a mylar covering (about 7 mg/cm^2). With the sliding beta shield closed, there is a covering of about 1,000 mg/cm^2 shielding the detector.

Typically, power plants have a procedure that describes the method of calculating beta dose rates, and these procedures typically have the beta dose rate calculated by open window minus closed window multiplied by a beta "correction factor". This beta correction factor is based on the size of the source, the distance to the detector and the energy of the beta radiation. Because the thickness of the chamber mylar (7 mg/cm^2) and the beta shield (1,000 mg/cm^2) are based on shallow dose and deep dose respectively, the instruments are optimized for determination of shallow and deep dose rate. Some procedures then go further and address how the lens of the eye dose rate would be calculated at a depth of 300 mg/cm^2. Currently, due to a relatively high lens dose limit compared to whole body dose limit, these lens dose rate estimates can be highly conservative (provide higher than actual dose rates). However, with a lower dose limit for the lens of the eye, the accuracy of these estimated dose rates to the lens becomes more important.

In the past, Ontario Hydro (OH) performed measurements of radiation fields in CANDU power plants using silicon detectors designed to reject gamma radiation and determine a beta spectrum. The approximate range of energy detectable was from 60 keV to 2.5 MeV. Using this information on beta spectra, it was possible to determine beta correction factors for extremity and whole body TLD badges. OPG and Bruce Power (both formerly part of OH) now use a four-element TLD badge, with two elements used for measuring beta skin dose. It is planned to perform updated beta spectroscopy measurements in 2013 and 2014. This information will aid in determining the extent of the beta hazard to the eyes for certain types of work. It may allow development of a new algorithm to calculate the beta dose to the eyes for the four-element TLD badge, or understand the measurement results for other eye dosimeters, as well as providing information on new protective equipment for the eyes. (Ref. Horowitz, et al, Radiation Protection Dosimetry).

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INFORMATION ON DOSIMETRY AND OPERATIONAL RADIATION PROTECTION

Introduction

The basis for this project is that the lens dose limit will be changed, and assuming that there will be a reduction in the limit, there are some issues that will need to be considered. These questions stem from the fact that the current lens dose limit is a factor of 3 or more times higher than the current whole body dose limit, and the lens dose has rarely been a limiting dose. That is, the whole body dose or skin dose typically reaches the limit before the lens dose reaches its limit. At a depth of 300 mg/cm^2, high energy beta radiation and electrons could result in doses that are higher than whole body (deep dose at 1000 mg/cm^2). If the lens dose limit is reduced to the same as whole body dose, then several issues should be considered.

- How accurate is the current dosimetry for lens dose, and does it need improvement?
- Is the lens of the eye currently considered for protection (e.g., goggles or face protection)?
- If there is non-uniform irradiation of the head, will a separate lens dosimeter be needed?
- Will the reduced lens dose limit have any effect on the use of multiple dosimetry for Effective Dose evaluations for external exposures?
- Employee relations must be considered, and workers should clearly understand the nature of the limit change so that there is no mistrust of past levels of protection.
- The levels where monitoring for the lens is required will decrease (e.g., in the U.S., monitoring is required at 10% of the occupational worker limit).

Beta radiation with a maximum energy of 0.79 MeV or higher has the capability to reach the lens of the eye through the depth of 300 mg/cm^2. 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). Some common radionuclides at power plants that have high beta or gamma radiations include cobalt-60, strontium/yttrium-90, krypton-87, krypton-88, rubidium-88, xenon-135, xenon-138, cesium-138, antimony-122, antimony-124, europium-152, rhodium-106, and nitrogen-16. The exposure of individuals to these radionuclides is dependent on the plant conditions and situations such as fuel damage, steam affected areas in BWR's, primary coolant leakage, and exposure to open sources such as primary coolant surfaces. While exposure to these high energy radiations is possible, each plant would need to determine the applicability based on its own operating history and plant conditions.

Industry Survey and Lens Dose Limit Considerations

EPRI conducted an industry survey to obtain information relative to protection programs, monitoring programs, and plant radiological conditions to better evaluate the potential effects of a reduced lens dose limit. The survey was sent out in December 2012, and results were received generally in the first quarter of 2013. About 2/3 of U.S. plants responded, along with 7 international utilities. The specific questions of the survey are shown in Appendix A, and a summary of the results of the survey are shown in graphical form in Appendix B. The key findings from the survey are described below.

Survey Response

Out of 65 U.S. nuclear plant sites, 43 responded to the survey. In the U.S., Duke Energy (including sites previously owned by Progress Energy) and Southern Nuclear each responded with one fleet response. Seven responses from utilities outside the U.S. were received:

- Angra (Brazil)
- Cofrentes (Spain)
- EDF (France)
- KHNP (Korea)
- OPG (Canada)
- Bruce Power (Canada)
- Forsmark (Sweden)

Administrative Dose Limits (ADL)

ADL's are set as a management control tool to assure that individuals are not approaching regulatory limits. For Total Effective Dose Equivalent (TEDE) for U.S. plants, generally one value was provided, as summarized below. In some cases, there were two values provided. For example, 2,000 mrem guideline, with 4,500 mrem as a maximum admin limit after additional approvals. Some utilities had an ADL for dose at that station (e.g., 2,000 mrem) and a total ADL from all licensees (e.g., 3,000 mrem). The summary below is for the lowest listed values.

- 1,000 mrem: 3 sites
- 1,500 mrem: 1 site
- 2,000 mrem: 38 sites
- 3,000 mrem: 1 site

The typical ADL of 2,000 mrem/yr is 40% of the 5,000 mrem/yr dose limit, and this indicates a strong pressure to maintain TEDE well below the federal limit.

TEDE for international utility responses generally listed the limits of 2,000 mrem/yr average over 5 years, and any one year limit is 5,000 mrem. Angra listed a 7,500 mrem per 5 years ADL. OPG listed 2,000 mrem/yr, with a 5,000 mrem per rolling 5 calendar years. OPG reported that certain trades or organizations had varying rolling limits (5,000 - 9,000 mrem/5 years). For EDF, although this survey didn't report an ADL, previous discussions with EDF indicated that annual ADL of 1,400 mrem was in use.

Lens Administrative Dose Limits

Lens ADL for U.S. sites:

- 3,000 mrem: 2 sites
- 6,000 mrem: 3 sites
- 12,000 mrem: 22 sites
- 13,500 mrem: 4 sites
  15,000 mrem: 12 sites

The typical ADL of 12,000 mrem/yr is 80% of the 15,000 mrem/yr lens dose limit, and some utilities do not have any ADL. This indicates that the lens dose does not need to be carefully monitored, most likely because there is little chance of reaching a value of 3 times the TEDE limit. That is, if TEDE is controlled and limited, the lens dose limit will not be approached.

Lens ADL for international sites: Angra lists the same ADL as for TEDE, 2,000 mrem/yr and 7,500 mrem per 5 yr. Other countries listed only the legal limit of 15,000 mrem/yr.

Skin and Extremity Administrative Dose Limits

Skin and extremity ADLs for U.S. sites:

- 10,000 mrem: 2 sites
- 12,000 mrem: 1 site
- 20,000 mrem: 3 sites
- 40,000 mrem: 16 sites
- 45,000 mrem: 9 sites
- 50,000 mrem: 12 sites

The typical ADL of 40,000 mrem/yr and higher are ≥80% of the 50,000 mrem/yr skin and extremity dose limits, and some utilities do not have any ADL. This indicates that the utilities do not see a need to control the skin and extremity doses at levels much below the limits. This is likely the case because plant conditions do not often include exposure to high contact and high beta (skin) doses; therefore, the skin and extremity doses are controlled by maintaining good control over the whole body doses.

Skin and Extremity ADL for international sites:

- OPG: 25,000 mrem extremities and 10,000 mrem skin. Note that OPG uses the term Exposure Control Level.
- Angra: 40,000 mrem
- Cofrentes, EDF, KHNP, Forsmark: 50,000 mrem

Dosimeter of Legal Record (DLR) System Used

U.S. utilities

All responses indicate that the dosimetry processor provides a lens of eye dose reading.

- OSL, Landauer: 19 sites
- TLD, Mirion/Global: 7 sites
- TLD, Utility Processing: 8 sites

International Utilities

Of the international responses, two Utilities indicated that the dosimetry processor provides a lens of eye dose reading. One Utility indicated that they will be performing a study in late 2013 on about 100 individuals using headband dosimeters from Public Health England that measure dose equivalent at a depth of 3 mm. The purpose of the study is to identify situations/professions where the whole body dosimeter [Hp(10) and Hp(0.07) on the chest] is not good enough for estimation of the eye lens dose [Hp(3) near the eye].

- TLD (Panasonic, Vinten, Harshaw): 3 Utilities
- TLD, Utility Processing: 1 Utility
- OSL, Landauer-Europe: 1 Utility

Slightly more than half the respondents use OSL, and the other portion use TLD for the dosimeter of legal record. About 3/4 of the respondents relied on a vendor for processing. The dosimetry vendors' ability to monitor lens of eye dose, either through a detector or with an algorithm, will be an important part of future improvements.

Lens Dose Monitored Directly or Via Algorithm

Is lens dose measured directly with a dosimeter or is it calculated with an algorithm? Do you have access to or knowledge of the algorithm details for lens dose?

The intent was to determine if there was a specific dosimeter or element of a dosimeter that was designated to measure lens dose, as opposed to an algorithm that uses one or more other elements (e.g., shallow depth and deep dose depth) to calculate the dose at 300 mg/cm^2.

U.S. responses

- Measured by dosimeter directly: 2 responses
- Calculated by algorithm: 35 responses
- Knowledge of algorithm:
  - Yes: 25
  - No: 10
  - Could obtain from vendor if needed: 6.

International responses

International utilities indicated a mix of responses that could not be easily categorized. Angra has an algorithm and has knowledge of it. Other responses either indicated that they either do not have an algorithm or that eye dose is not required to be reported.

About 60% of the respondents had direct knowledge of the algorithm used to measure/calculate lens dose. The algorithm will become more important if the lens dose limit is exceeded. A very conservative algorithm will not be beneficial because it will unnecessarily restrict the worker by overestimating his lens dose. Algorithms can be expected to receive increased regulatory attention considering the lower dose limit; therefore, non-conservative algorithms will be questioned. Overall, this question's response emphasizes the need to become familiar with the dosimetry algorithm and how it calculates the lens dose for radiations present at each plant.

Highest Lens Dose Reported

Report the highest lens doses and deep doses for the years 2010 and 2011. The results from this question did not yield any substantial differences between dose to the lens and the deep dose. Often the numbers were the same or only slightly higher for the lens dose. A summary of the data is shown in Appendix B.

These results indicate that the lens dose often is the same as deep dose. Most plants use an algorithm that takes the shallow dose and deep dose dosimeter readings and performs a calculation. If there is no substantial difference between the two, there are likely low amounts of high energy beta, and the lens dose would be similar to deep dose. There are times when lens dose was higher sometimes due to non-uniform radiation fields (e.g., dose from overhead). There are no specific actions apparent based on this data.

Use of Eye Protection

This question asked about use of safety glasses for skin protection from radiation and for eye lens protection. U.S. and International responses are grouped together:

- Do you use safety glasses or face shields for skin protection? 29 yes; 11 no.
- Do you use safety glasses or face shields for eye lens protection? 30 yes; 10 no.

  Note that for questions on safety glasses or face shields, some respondents considered that safety gear worn for industrial safety purposes was also supplying skin and/or lens protection, whether or not the purpose was for radiation protection.
- Do you take credit for the safety glasses/face shields in determining lens of eye dose? 5 yes; 34 no.
- Are there other methods of eye protection used for lens dose reduction? 6 yes; 33 no.

  Methods included Powered Air Purifying Respirators, Delta Suits, full face respirator, and visors on Tyvek hoods.

These results indicate that although utilities typically used safety glasses/face shields in practice, they normally did not "take credit" for the reduction in lens of eye dose. The most likely reason is that they were not actively tracking lens dose because it was not limiting, so it would be an administrative burden to lower the lens dose when it was already well below the limit. With a lower lens dose limit, there will be more need for consideration of lens dose reduction by face shields, safety glasses, and other devices (respirators, visors, Tyvek hoods, etc.).

Estimates of Lens Dose and Skin Dose In Advance of Work

This question asked about procedures for estimating lens of eye dose and skin dose in advance of work in an area. U.S. and International responses are grouped together:

- Do you have a procedure for estimating lens dose potential prior to work in an area? 5 yes; 35 no.
- Do you have a procedure for estimating skin dose potential prior to work in an area? 16 yes; 24 no.
- 7 procedures were provided as additional information.

Most utilities do not estimate what the lens dose is prior to entry, most likely because normal protection for whole body and skin will keep the lens dose well below the limit. If a lower lens dose limit was in effect, procedures may need to be changed to evaluate the lens dose potential prior to entry and to evaluate the lens dose monitoring (e.g. is badge placed correctly and covered correctly?). There are some existing procedures reviewed that are a good basis for eye protection and monitoring, and those procedures would need to be adjusted to account for the lower lens dose limit.

Plant Areas with High Energy Beta

Are there plant areas where workers could be exposed to high energy beta, and under what conditions would personnel be exposed to high energy beta? U.S. and International responses are grouped together:

- 24 responses said there are no current areas where workers could be exposed to high energy beta.
- 6 responses said yes for high energy beta exposure and 8 responses were "possibly" or "unlikely".

Conditions where high energy beta could be encountered were listed as:

- Primary system
- Steam Generator primary side work
- Failed fuel
- Fuel pool, reactor cavity, and fuel transfer canal
- Steam affected areas
- Turbine blade work
- Source checks with Sr/Y-90 source

Although most respondents stated that there are no current areas where workers could be exposed to high energy beta, the goal should be to prepare utilities to properly monitor and protect the lens of the eye in both routine and off-normal conditions. The listed conditions above are those that could be encountered at many plants at some time. Therefore, the recommended actions are to ensure that procedures are set up so that RP personnel recognize those times when high energy beta or air scattered electron may be present, and take the necessary precautions for lens of eye protection and/or monitoring.

Effective Dose Equivalent from External Exposure (EDEX)

Has calculation of EDEX been performed at the site, and if so, what method has been used?

The term EDEX has been used by U.S. utilities to describe the calculation of Effective Dose Equivalent (EDE) as described in ICRP-26, with respect to external radiation exposure. ICRP-60 and ICRP-103 changed the name of the term Effective Dose Equivalent (EDE) to Effective Dose (E); however, the definition is fundamentally the same. For both EDE and E, the organ doses (ICRP-26) or the equivalent dose in organs or tissues (ICRP-60, ICRP-103) are multiplied by a tissue weighting factor to obtain the Effective Dose (Equivalent). The numbers of organs and the values of the weighting factors are different in each of the ICRP reports, but the general calculation method is the same.

For external radiation only, this report will use the term EDEX, and there are two basic methods that have been used in the U.S. to determine the EDEX value. The first is the compartment method, where each body compartment (i.e., head and neck, thorax, abdomen and pelvis, upper arms, upper legs) is given a compartment weighting factor based on the sum of the weighting factors for the organs in that compartment. ANSI N13.41-2011, "Criteria for Performing Multiple Dosimetry" is an example of that method. In Canada, a similar method is used, but the basis for the weighting factors is ICRP-60 rather than ICRP-26.

The second method is the two dosimeter method, where a dosimeter is worn on the front and back of the body. This method relies on calculations where the Monte Carlo radiation transport computer code MCNP was used to calculate the dose to individual tissues modeled in the phantoms, and simulated dosimeter readings, for a range of different exposure geometries.

The EDEX (the sum of the products of the calculated phantom tissue doses and their respective ICRP weighting factors) were calculated for photons incident on the phantoms from various locations. Empirical algorithms were developed to relate the EDEX to a weighted average of dosimeters on the front and back of the body. This two-dosimeter method was described by EPRI in Technical Report TR-101909, Volumes 1 and 2, and the Implementation Guide TR-109446. A similar method is used by South Korea, which uses the same general methodology, but uses a different dosimeter weighted average as described in NCRP Report No. 122, "Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low LET Radiation."

U.S. Sites

Of the 43 U.S. sites, 38 stated that they use EDEX, although there is a wide range of frequency of use. Of those 38 sites, 31 use the ANSI N13.41 method, and 8 stated they use RG 8.40, which permits both the ANSI N13.41 method and the EPRI 2-dosimeter method, and four sites indicated that they did not use EDEX. Although there are a range of frequencies of use, the typical plant uses the ANSI method primarily during outages, for specific jobs in which there is a dose accuracy benefit.

U.S. plants have the approval to use EDEX methods via Regulatory Guide 8.40; however, in almost all cases, only the ANSI-N13.41 method is used. If a lower lens limit is used (e.g., 5 rem per year in the U.S.), then although the EDEX compartment model (ANSI) could be used, the dose to the lens may limit the dose to the individual. The lens is not listed as an organ to be weighted, and any high dose gradient in vicinity of the head (especially near the eyes) would result in a high lens dose. In that situation, the EDEX calculation would result in a lower effective dose result, but the lens dose would be higher (limiting).

An example of a task with a high dose gradient from above is work on a reactor head O-ring seal. Typically for this task, the worker is below the reactor head and is in close proximity in order to clean the grooves in the reactor head and to install the seal. At one U.S. Pressurized Water Reactor, actual measurements were taken beneath the reactor head in the area of the worker's head and the torso, and these indicate a strong dose gradient from above. These actual dose rates are shown in Table 4-1, along with the calculation of EDEX with ICRP-26 weighting factors. Note that NRC Regulatory Guide 8.40 allows the use of the ICRP-26 weighting factors because they are listed in 10 CFR 20. Licensees in the U.S. that have approval to use other weighting factors would need to get special approval from the NRC. Other countries that use ICRP-60 or ICRP-103 could perform a similar calculation with alternative weighting factors. The most recent update to ANSI N13.41 in 2011, *Criteria for Performing Multiple Dosimetry*, includes an appendix with 3 sets of weighting factors (ICRP-26, ICRP-60, ICRP-103). In the simplified example in Table 4-1, the dose rate to the head and neck (including the eye lens) is much higher than the general area dose rate, which applies to all other organs and compartments. The example shows that the lens dose rate is 9.8 mSv/hr (980 mrem/hr) compared to the EDEX calculation of 2.74 mSv/hr (274 mrem/hr). When considering stay time for an individual on this job, if the EDEX value is used, the stay time is over 18 hours to reach 50 mSv (5 rem). If the lens dose limit is reduced to 50 mSv (5 rem), then the stay time would be about 5 hours. This shows that in certain situations, particularly those with a dose gradient from above, the lens dose could be limiting. Therefore, plants will need to determine the lens dose regardless of whether or not they choose to perform multiple badging and determine EDEX.

Table 4-1
Example: Reactor Head O-Ring Seal Work - Stay Time Comparison based on EDEX and Lens Dose with a 50 mSv (5 rem) Limit

Compartment	ANSI 13.41 Weighting Method (ICRP 26)	Dose Rate from Above (mrad/hr)	Compartment EDEX (mrem/hr)
Head & Neck	0.10	980	98
Thorax	0.38	196	74
Abdomen	0.50	196	98
Upper Right Arm	0.005	196	1.0
Upper Left Arm	0.005	196	1.0
Right Thigh	0.005	196	1.0
Left Thigh	0.005	196	1.0
Total EDE		274 mrem/hr	
Lens of Eye		980 mrem/hr	
Stay Time EDE (5 rem)		18.2 hr	
Stay Time Lens (5 rem)		5.1 hr	

Note: EDEX calculation uses ICRP-26 Tissue Weighting Factors as per ANSI 13.41-1997.

International responses

For reasons described in the previous section, for international responses, the term "EDEX" was not recognized because the ICRP instead uses the term "Effective Dose". However, in describing the responses below, the term EDEX is used and should be considered comparable to the concept of multiplying the equivalent dose in organs/tissues with a tissue weighting factor.

- Three Utilities are not currently using EDEX. However, one of those utilities reviewed situations where it may be beneficial. Preliminary studies have shown that it will be useful to consider EDEX for pressurizer heater replacements.
- One Utility has a long history of using EDEX, and they use the NCRP-122 method, which is similar to the EPRI 2-dosimeter method. Their guidance is to use two dosimeters when the following conditions are met:
  - Expected difference between the chest badge and a specific body part is >30%.
  - Exposure rates are >1 mSv/hr (100 mrem/hr)
  - A total dose of > 2 mSv (200 mrem) is expected in a single task.
- Another Utility uses a compartmental model similar to ANSI N13.41, but uses ICRP-60 weighting factors to about 4.6% of the workers.

5
GAPS AND RECOMMENDED ACTIONS

Gap: Dosimeter design and algorithm

Existing personnel dosimetry design and algorithms may not adequately monitor lens dose, considering the increased scrutiny anticipated with a reduced lens dose limit.

Recommended Actions: (Utility personnel and dosimetry vendors)

1. Use or develop dosimeters placed physically near the eyes (e.g., headband) to ensure accurate monitoring of the lens dose.
2. Investigate availability or development of a device to track lens dose on a real time basis.
3. Perform testing of dosimeters using radiation fields expected at power plants to determine the accuracy of dosimeter and algorithm for evaluating lens dose. This could include laboratory testing and/or field testing at power plants. Based on results of testing, additional dosimeter development may be necessary.

Gap: Operational Protection and Monitoring of the Lens of the Eye is not Optimized for a Reduced Lens Limit

Most utilities do not have procedures that consider the protection/shielding of the eye lens as part of the work planning. Procedures will be needed considering that with a lower lens limit, there will be no margin between the whole body dose and the lens dose.

Recommended Actions:

1. Review existing procedures and develop a "best practices" procedure for protection of the lens of the eye. This best practice procedure would consider the reduced lens limit, radiation fields to be encounter, protective equipment (e.g., face shield), and personnel monitoring (e.g., protective covering over the dosimeter). Note that the density thickness over the dosimeter should be compared to the density thickness covering the eye lens to ensure an accurate measurement of lens dose.
2. Evaluate whether the existing instrumentation is adequate when considering the need for more accurate measurements of lens dose rate. Review existing technical data on beta energy spectra in power plants. Consider whether additional information relating beta spectra to instrument response is needed. Also consider whether alternate methods for instrument calibration are needed.
3. Review situations where there is a non-uniform irradiation of the head, and determine what conditions would make an eye dosimeter more appropriate than one dosimeter elsewhere on the head.

Gap: Monitoring Effective Dose Equivalent for External Exposure (EDEX)

Existing EDEX procedures do not consider the case where a dose to one area of the body (e.g. head and eyes) has the same dose limit as that for the "whole body". A lower lens dose limit will change the determination of when multiple badging and EDEX calculations will be performed.

Recommended Actions:

1. Perform a review of common multiple badging and EDEX practices/procedures. Provide clarification that lens dose is not associated with an effective dose calculation (EDEX). The lens dose will be required to be determined, whether or not an EDEX determination is made.

6
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A

EPRI INDUSTRY SURVEY QUESTIONS ON LENS DOSE ISSUES -

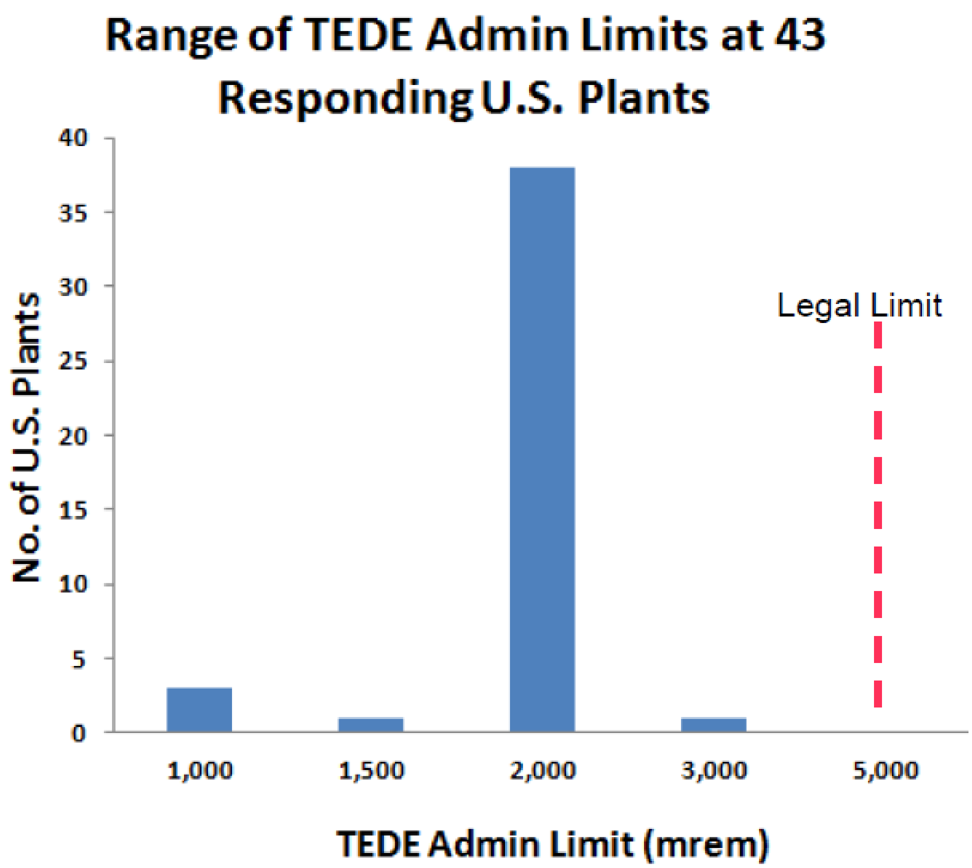
1. Who is the primary contact for lens of eye dose limit issues for dosimetry and protection?
2. What are the administrative radiation dose limits for TEDE, lens of eye, extremities, and skin?
3. Dosimeter of Legal Record (DLR) used onsite
   a. Specify if it is TLD, OSL, or other.
   b. Name of dosimetry vendor (or utility if in-house).
   c. Does the dosimetry vendor provide a lens of eye dose value?
4. DLR lens dose algorithm
   a. Do you measure lens dose directly with a dosimeter or is the value calculated (algorithm)?
   b. Do you have access to and knowledge of the algorithm detail for lens dose?
5. Lens Dose Results
   a. List the highest lens dose recorded in 2010.
   b. For that same individual as above in (a), what was the deep dose equivalent in 2010?
   c. List the highest lens dose recorded in 2011.
   d. For that same individual as above in (c), what was the deep dose equivalent in 2011?
6. Eye Protection
   a. Do you use safety glasses or face shields for the purposes of skin protection?
   b. Do you use safety glasses or face shields for the purpose so lens protection?
   c. Do you "take credit" for the safety glasses or face shields in determining lens of eye dose?
   d. Are other methods of eye protection used (for the purpose of lens dose reduction)?
7. Eye Protection - estimating when necessary

   a. Do you have a procedure for estimated the lens of the eye dose in advance of work in an area?
   b. Do you have a procedure for estimated the skin dose in advance of work in an area?
   c. Please provide electronic copy of procedures referenced in this question.

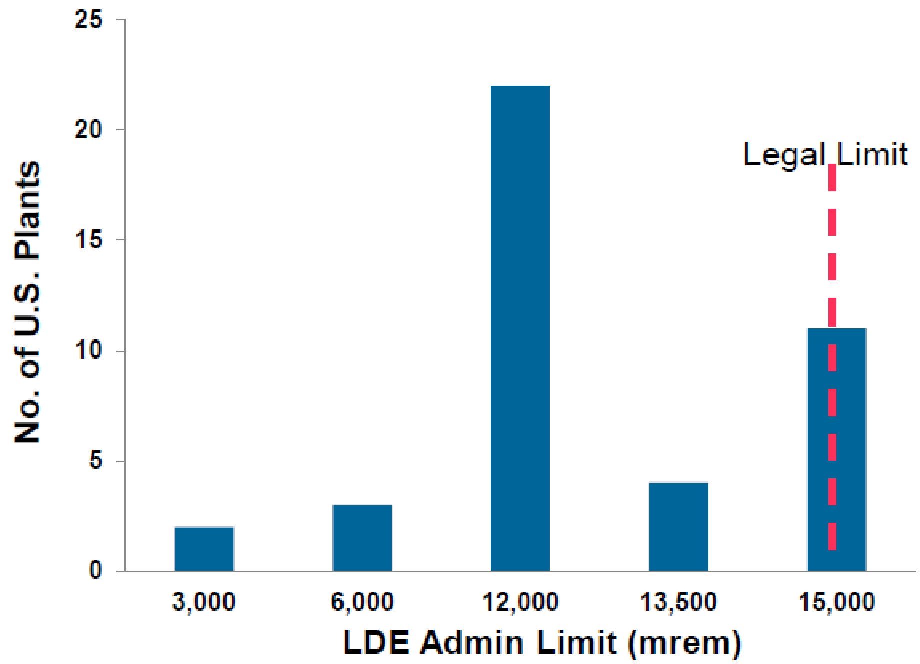
8. Plant conditions
   a. Do you have plant areas where workers could be exposed to high energy beta (>0.75 MeV)?
   b. Under what conditions would personnel be exposed to high energy beta? (e.g., power entry, fuel pool work, etc.)

9. Effective Dose Equivalent for External Exposure (EDEX)
   a. Does your plant use EDEX to calculate effective dose equivalent?
   b. If yes, then what method is used (ANSI N13.41, EPRI 2-dosimeter method)?
   c. How extensively is the EDEX concept used? (e.g., outage only, 40 people)

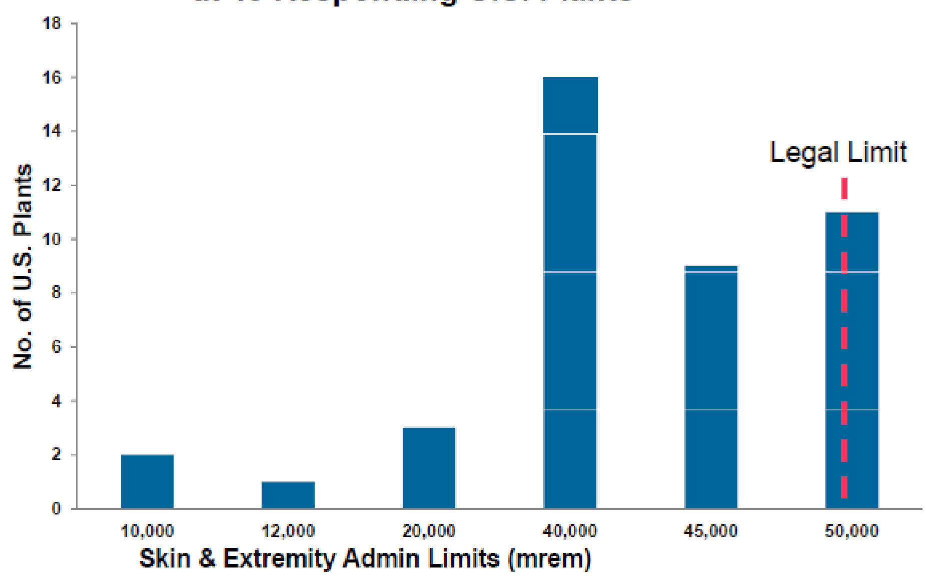
B
SUMMARY OF INDUSTRY SURVEY RESULTS ON LENS DOSE ISSUES



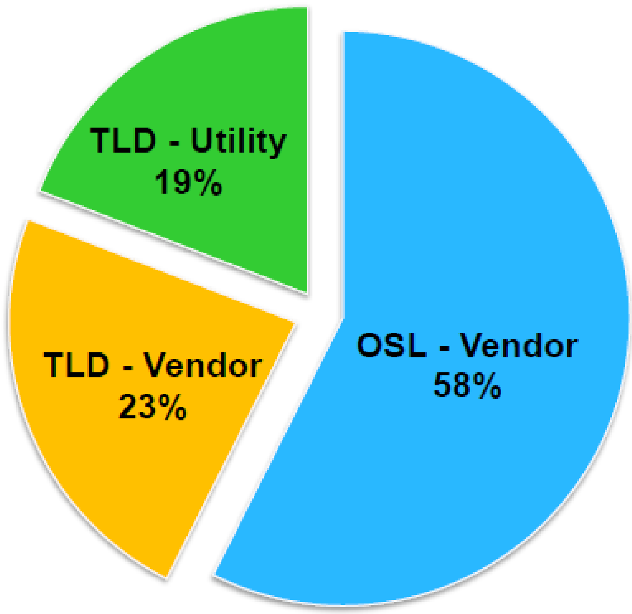
Range of Lens Dose Admin Limits at 43 Responding U.S. Plants



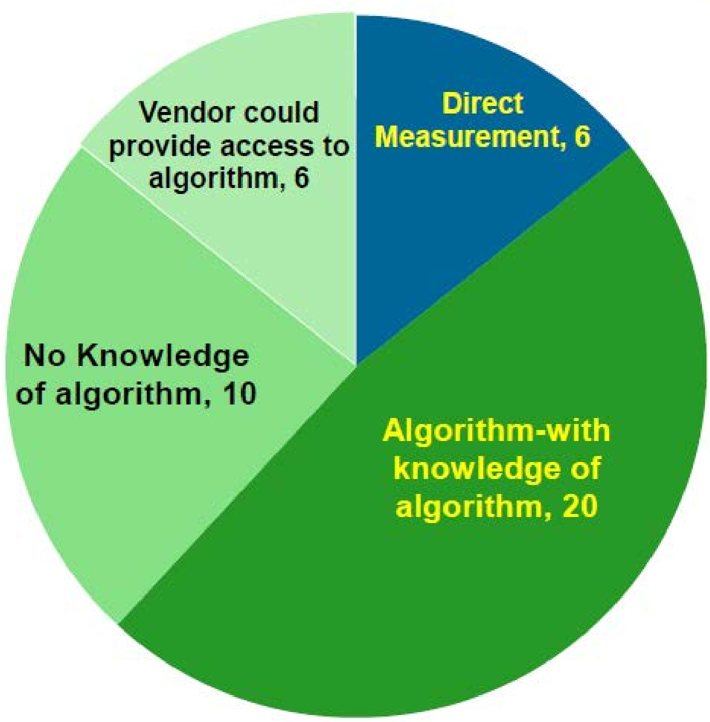
Range of Skin & Extremity Dose Admin Limits at 43 Responding U.S. Plants



Types of Dosimetry Used by Responding U.S and International Utilities



Nuclear Industry Survey – How is Lens Dose Measured – and do you know the algorithm?

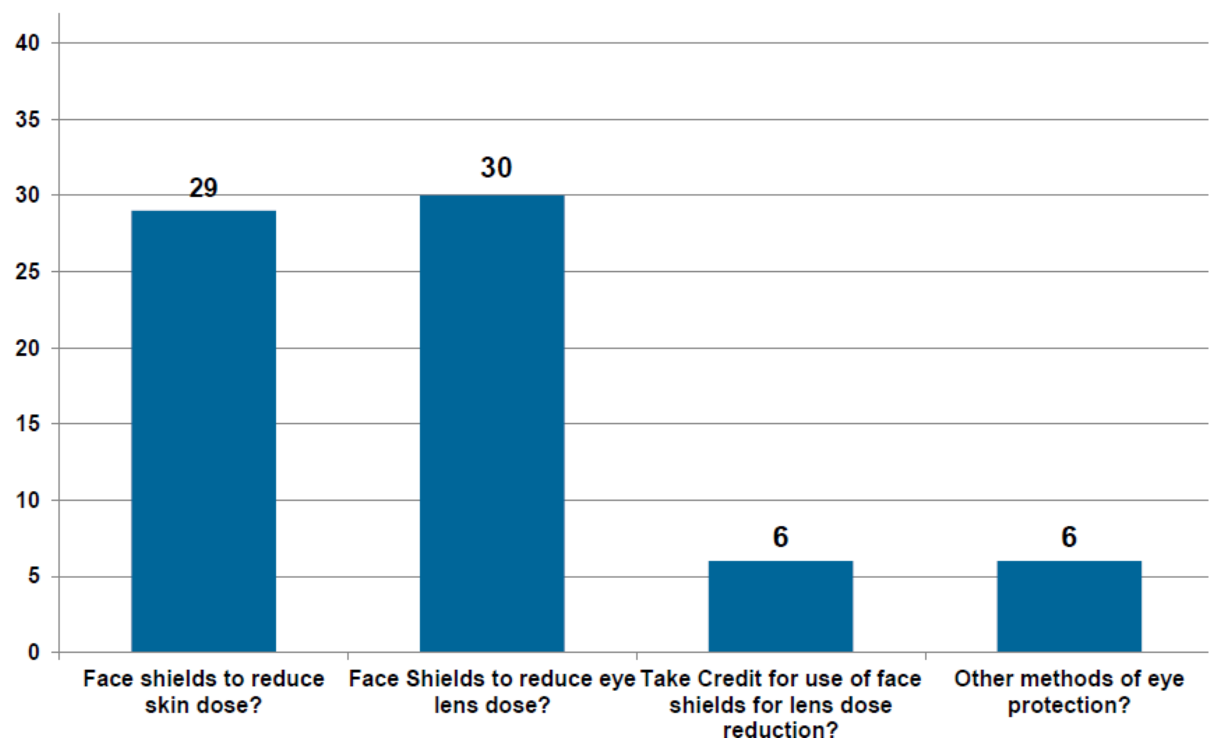


Nuclear Industry Survey – What was highest lens dose and TEDE in 2010 and 2011?

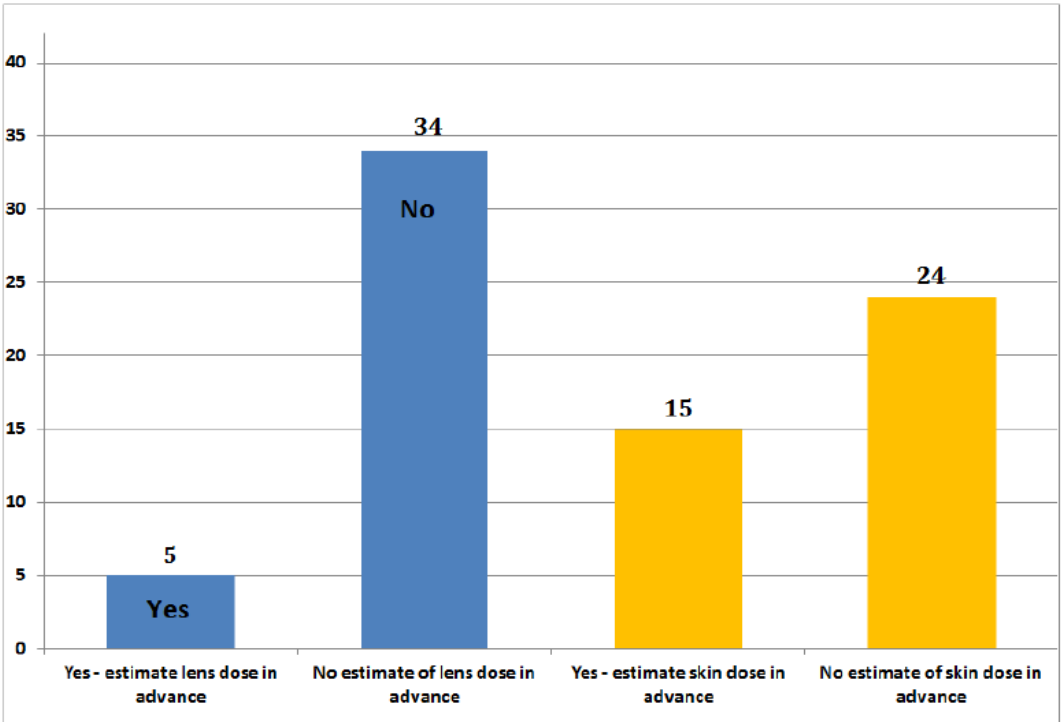
- The results of this question were not enlightening.
- In almost all cases, the lens dose and TEDE were within 1% of each other.
- In some cases, repositioning the dosimeter to the head resulted in high lens dose if EDEX was used.

For US Plants	2010 Highest Lens Dose	2010 Deep Dose for Same Individual	2011 Highest Lens Dose	2011 Deep Dose for Same Individual
Average	921	916	862	837
Minimum	130	130	171	171
Maximum	2,231	2,227	1,821	1,698

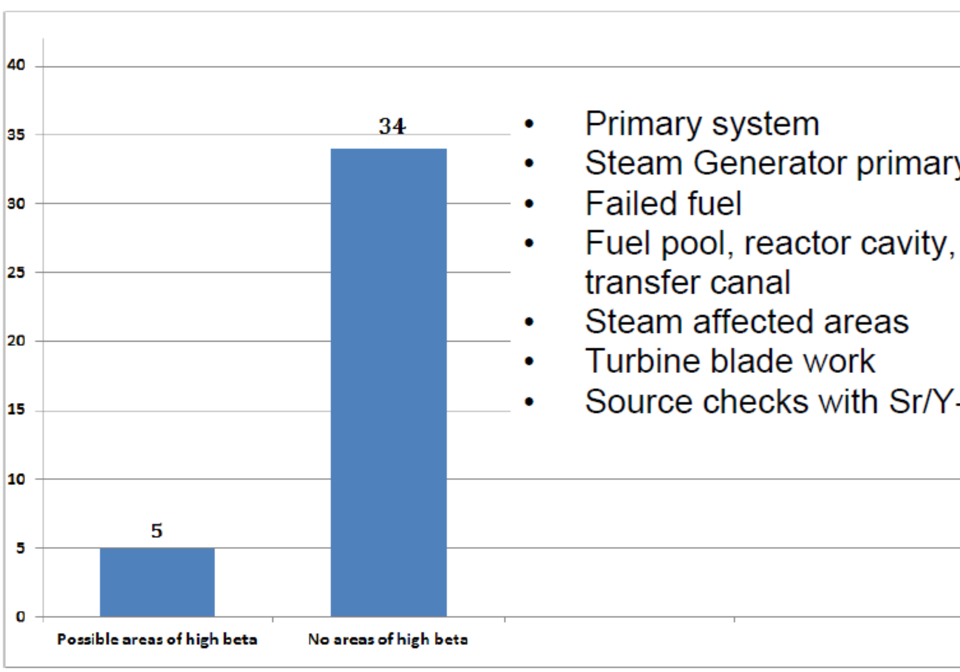
Nuclear Industry Survey
Use of Safety Glasses and Face Shields



Nuclear Industry Survey - Estimation of Lens Dose and Skin Dose in Advance of Work

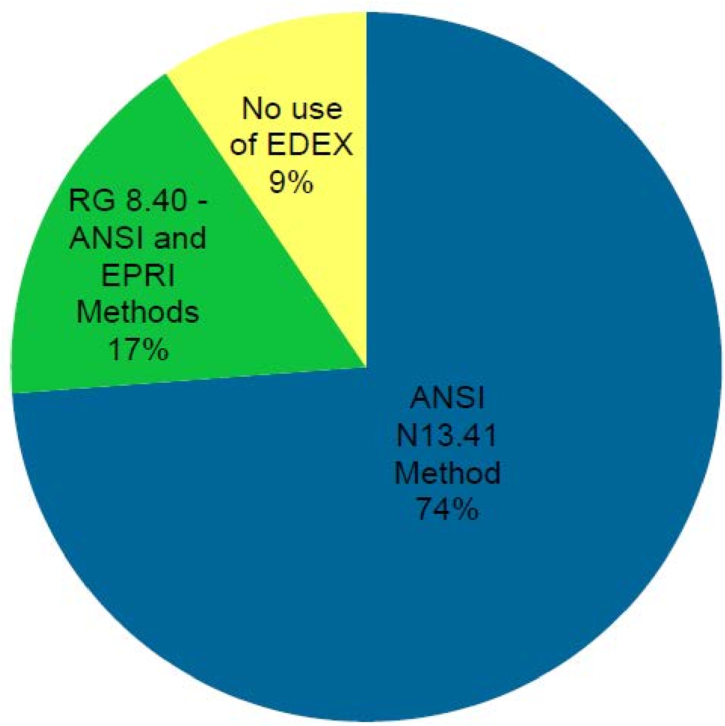


Nuclear Industry Survey Plant Areas with High Beta Energy



- Primary system
- Steam Generator primary side work
- Failed fuel
- Fuel pool, reactor cavity, and fuel transfer canal
- Steam affected areas
- Turbine blade work
- Source checks with Sr/Y-90 source

Nuclear Industry Survey
Use of Effective Dose Equivalent



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