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1. INTRODUCTION

This standard specifies the thermoluminescence dosimetry requirements for the Eskom Generation Division in terms of the Eskom Radiation Protection Policy 32-227 and Standard 32-226. The Eskom Generation Division is committed to ensure that nuclear and radiation safety receives the highest priority to provide for the protection of persons and the environment against harmful ionising radiation in accordance with the safety principles and requirements addressed in the Eskom Radiation Protection Policy and Standard.

2. SCOPE

2.1 PURPOSE

This standard specifies the requirements for the thermoluminescence dosimetry programme employed at the Koeberg Nuclear Power Station in terms of Eskom Policy 32-227, Eskom standard 32-226 and the Generation Division Radiation Protection Manual, 238-19 relating to radiation protection and safety of radiation sources.

2.2 APPLICABILITY

This standard is applicable to Group III hazardous substances (electronic products), Group IV hazardous substances (radioactive sources), radioactive material, restricted material, special nuclear material and radioactive waste defined in the Generation Division Radiation Protection Manual, 238-19.

3. NORMATIVE/INFORMATIVE REFERENCES

The following normative references contain provisions that, through reference in the text, constitute requirements listed in this document. Parties using this document shall apply the most recent edition of the documents listed below, unless otherwise specified in the applicable statutory and regulatory requirements:

3.1 NORMATIVE

[1] 238-19: Generation Division Radiation Protection Manual, 238-19.

[2] 32-227: Eskom Policy, Radiation Protection and safety of radiation sources.

[3] 32-226: Eskom Standard, Radiation Protection and safety of radiation sources.

3.2 INFORMATIVE

The following informative references were used during the development of this document. Although listed, the informative references are not mandatory requirements.

[4] Nuclear Division Integrated Management System, Manual 238-1.

4. DEFINITIONS AND ABBREVIATIONS

4.1 DEFINITIONS

4.1.1 **Dosemeter(s):** An instrument to detect and measure accumulated radiation exposure. Used for personal monitoring and must be worn on the body.

4.1.2 **Dosimetry:** See dosemeter

4.1.3 **Dose:** A measure of the radiation received or absorbed by a target.

4.1.4 **Electronic Product:** Any electronic product that emits ionising electro-magnetic, particulate radiation or any sonic, infrasonic or ultrasonic wave.

4.1.5 **Employee:** A person who has entered into or works under a contract of service, or of apprenticeship or learnership with an employer, whether the contract is express or implied, oral or in writing, and whether the remuneration is calculated by time or by work done, or is in cash or in kind, and includes:

a. a casual employee employed for the purpose of the employer's business;

b. a person who has entered into a contract of service or of apprenticeship or learnership with the employer;

c. a person provided to Eskom by a Temporary Employment Service (Labour Broker) and who works under the control, instruction and supervision of an Eskom employee;

d. a casual employee;

e. a part-time worker;

f. a temporary worker;

g. an occasional employee;

h. an unattached learner;

i. a bursar.

Note: *In the event of an injury to persons in the above categories, it will be regarded as arising out of and in the course of duty, if the injured person worked under the instruction and supervision of an Eskom employee.*

4.1.6 **Eskom**: is used for Eskom Holdings SOC Limited, its divisions and wholly owned subsidiaries.

4.1.7 **Exposure:** The act or condition of being subject to irradiation externally or internally. The term also expresses the amount of ionisation produced in air by ionising radiation.

4.1.8 **External Exposure:** Irradiation by sources outside the body.

4.1.9 **Group III Hazardous Substance:** Any electronic product that emits ionising and non-ionising radiation.

4.1.10 **Group IV Hazardous Substance:** Any fabricated radioisotopes.

4.1.11 **Ionising Radiation:** Radiation capable of producing ion pairs in biological material(s).

4.1.12 **Occupational Exposure:** All exposures of radiation to employees incurred during work.

4.1.13 **Potential Exposure:** Exposure to radiation that is not expected with certainty to be delivered, but that may result from an incident at a source or owing to an event or sequence of events of a probabilistic nature, including equipment failures and operating errors.

4.1.14 **Protection And Safety:** The protection of people against exposure to ionising radiation or radioactive substances and the safety of radiation sources, including the means for achieving

such protection and safety, such as the various procedures and devices for keeping peoples' doses and risks as low as reasonably achievable.

4.1.15 **Public Exposure:** Exposure incurred by members of the public from radiation sources.

4.1.16 **Radiation:** See ionising radiation.

4.1.17 **Radiation Worker:** Any worker who is potentially exposed to radiation through his/her occupation on Eskom premises, to more than 1 mSv per annum.

4.1.18 **Regulatory Authority:** Authority designated by government for regulatory purposes in connection with radiological protection and occupational health and safety i.e. the National Nuclear Regulator and the Directorate: Radiation Control, Department of Health.

4.1.19 **Source:** Anything that may cause radiation exposure, by emitting ionising radiation or releasing radioactive substances or materials.

4.2 ABBREVIATIONS

Abbreviation	Description
CSIR	Council for Scientific and Industrial Research
ESKOM	Eskom Holdings SOC Limited, its divisions and wholly owned subsidiaries
Gy	Gray
keV	kilo-electronvolt
MeV	Mega-electronvolt
$mg.cm^{-2}$	milligram per square centimetre
mGy	milligray
mm	millimetre
mSv	millisievert
mSv/h	millisievert per hour
Sv	sievert
TLD	Thermoluminescence Dosemeter

5. REQUIREMENTS

5.1 GENERAL TEST CONDITIONS

5.1.1 All tests shall be performed under standard test conditions, unless when otherwise stated. Systems, dosemeters and readers shall be tested in a manner in which they are expected to be used during normal operation.

5.2 REFERENCE RADIATIONS

5.2.1 All tests involving the use of irradiated dosemeters shall be carried out using appropriate radiation sources.

5.2.2 Calibration of radioactive sources shall be traceable to the appropriate primary or secondary standards.

5.3 TYPE OF TESTS REQUIRED

5.3.1 Tests shall be performed as type tests and quality control tests.

5.3.2 Type tests shall be carried out to establish the characteristics of a type of dosemeter. The following tests fall within this category:

5.3.2.1 Stability of stored information

5.3.2.2 Stability of Zero Point

5.3.2.3 Detection Threshold

5.3.2.4 Repeatability

5.3.2.5 Linearity

5.3.2.6 Dose Range

5.3.2.7 Effect of Exposure to light

5.3.2.8 Spectral Response to Photon Radiation

5.3.2.9 Isotropy with Respect to Photon Radiation

5.3.2.10 Spectral Response to Beta Radiation

5.3.2.11 Isotropy with respect to Beta Radiation

5.3.2.12 Remanance

5.3.2.13 Effect of climatic changes

5.3.3 Quality control tests shall be carried out to verify that the performance of a specific production or delivery batch of dosemeters is consistent with that type. These tests shall be performed on each production or delivery batch of dosemeters and shall be restricted to those characteristics that may vary between batches, or within a batch. The following tests fall within this category:

5.3.3.1 Batch Homogeneity

5.3.3.2 Stability of Stored Information

5.3.3.3 Stability of Zero Point

5.3.3.4 Detection Threshold

5.3.3.5 Repeatability

5.4 NUMBERS OF DOSEMETERS OR DETECTORS REQUIRED FOR EACH TEST

5.4.1 The number of dosemeters used for each test, or in certain cases the number of repeated tests, shall be such that the performance requirements are demonstrated to be met with 95 % confidence.

5.5 TEST METHODS

5.5.1 Batch homogeneity

5.5.1.1 All dosemeters shall be irradiated to a known dose of approximately 2 mSv.

5.5.1.2 All dosemeters shall have an individual element response of within ± 15 % of the mean batch response for that element.

5.5.2 Stability of stored information

5.5.2.1 The evaluated values of dosemeters irradiated to a known dose equivalent, shall not alter by more than 5 % for 30 days at storage under standard conditions, or 10 % for 90 days at storage under standard conditions.

5.5.3 Stability of zero point

5.5.3.1 The zero point for elements used to determine shallow dose equivalent shall not change by more than 5×10^{-1} mSv, and for elements used to determine deep dose equivalent shall not change by more than 10^{-1} mSv, in thirty days after allowing for change due to background radiation.

5.5.4 Detection threshold

5.5.4.1 The detection threshold for elements used to determine shallow dose equivalent shall not exceed 5×10^{-1} mSv, and detection threshold for elements used to determine deep dose equivalent shall not exceed 10^{-1} mSv.

5.5.5 Repeatability

5.5.5.1 The standard deviation on response of individual dosemeter elements shall not exceed 7.5 % for a dose equivalent of 2 mSv.

5.5.6 Linearity

5.5.6.1 Within the dose equivalent range 1 mSv to 100 mSv, the response shall not differ from the response at 10 mSv by more than ± 5 %.

5.5.7 Dose range

5.5.7.1 The evaluated dose equivalent, shall be a monotonically increasing function of actual dose equivalent up to a minimum of 10 Sv.

5.5.8 Remanance

5.5.8.1 When a dosemeter reads a dose equivalent of 100 mSv, the zero point reading shall not be greater than 10^{-1} mSv.

5.5.9 Spectral response to photon radiation

5.5.9.1 The response for any photon energy within the range 15 keV to 3 MeV shall be within the range 0.7 to 1.3 (determined as Emax).

5.5.10 Spectral response to beta radiation

5.5.10.1 The response at any given beta energy shall be within the range 0.7 to 1.3

5.5.11 Isotropy with respect to photon radiation

5.5.11.1 When the dosemeter is exposed to photon radiation of energy 40 keV ± 20 keV, the mean value of response at angles of incidence (relative to the normal) of 20°, 40° and 60° shall not differ from the response at normal incidence by more than ± 10 %.

5.5.12 Isotropy with respect to beta radiation

5.5.12.1 The response of dosemeters, when exposed at an angle of incidence of 45° (relative to the normal), to beta radiation from appropriate sources, shall not differ from the response (at normal incidence) by more than ± 30 %.

5.5.13 Effect of exposure to light

5.5.13.1 Exposure of the dosemeter to 10 000 lux of artificial sunlight for one week shall not change the zero point by more than 5×10^{-1} mSv for elements used to determine shallow dose equivalent, and by more than 10^{-1} mSv for elements used to determine deep dose equivalent.

5.5.14 Effects of temperature and humidity

5.5.14.1 Storage at 50 °C in 65 % relative humidity for thirty days shall not alter the read-out value by more than 20 %.

5.5.14.2 Storage at 20 °C in 90 % relative humidity for thirty days shall not alter the read-out value by more than 20 %.

5.6 THE THERMO-LUMINESCENT DOSEMETER

5.6.1 The dosemeter shall provide information for evaluation of dose at the following depths in tissue equivalent material:

5.6.1.1 0.07 mm to estimate shallow dose equivalent to the skin.

5.6.1.2 3 mm to estimate dose equivalent to lens of the eye.

5.6.1.3 10 mm to estimate deep effective dose.

5.6.1.4 Where a dosemeter contains more than one demountable element, the correct identification of each element and its association with its position or filter, shall be ensured.

5.6.1.5 The dosemeter shall be of an approved design whose response characteristics and limitations are fully understood.

5.6.1.6 The dosemeter shall be clearly labelled and identifiable with respect to an individual carrier.

5.6.1.7 The dosemeter response with respect to neutron radiation relative to that due to photon and beta radiation, shall be known so that dose equivalent due to photon and beta radiation in the presence of neutrons can be evaluated.

5.7 CALIBRATION

5.7.1 During routine irradiation of dosemeters for the purposes of calibration, the dosemeter shall be orientated within the radiation field so that the incident radiation is normal to the dosemeter surface.

5.7.2 The dosemeter to source distance shall not be less than 150 mm to avoid secondary electrons emitted from the source from reaching the dosemeter.

5.7.3 For calibration purposes, the dosemeter shall be positioned at least 1 m from the floor, walls or any other massive structure which may scatter radiation.

5.7.4 During every calibration the delivered dose or dose rate at the dosemeter surface should be determined by calculation, and/or measurement using an instrument or source which is traceable to the appropriate primary or secondary standard.

5.8 CALIBRATION OF THE READER

5.8.1 Calibration of the reader shall be performed using special manufactured reader calibration dosemeters, or using a number of dosemeters selected from a batch of TLDs whose responses are found to exhibit a population standard deviation of equal to, or less than 3 %.

5.8.2 The reader calibration factor for both the photon and frequency counter's linear regions shall be based on an average value derived from several dosemeters irradiated within the appropriate exposure range.

5.8.3 The reader shall be calibrated routinely, after instrument repair, or whenever the calibration accuracy is questionable.

5.9 CALIBRATION OF THE DOSEMETER

5.9.1 A single correction factor for each element shall be assigned to a whole batch of dosemeters if the batch satisfies the following criteria:

5.9.1.1 The batch exhibits a population standard deviation $\leq$ 5 % as determined by the manufacturer.

5.9.1.2 Individual element responses of a batch of dosemeters exhibit a deviation within $\pm$ 15 % of the mean batch response.

5.9.1.3 Those dosemeters not satisfying the above criteria shall have individual element correction factors assigned for each dosemeter prior to issue.

5.9.1.4 The element correction factors shall be based on an average value determined from a minimum of four irradiations of the same exposure.

5.9.1.5 The dosemeter calibrations shall be performed by exposure of the dosemeter at a fixed distance from a source of gamma radiation. The dosemeter geometry and exposure time shall be accurately reproducible.

5.9.1.6 For the assessment of shallow dose equivalent arising from beta radiation, the batch element response shall be based on an average response of a representative sample calibrated as a minimum against appropriate radioactive sources.

5.9.1.7 The element correction factors initially assigned to each dosemeter shall be verified routinely. If the response of any dosemeter does not fall within ± 15 % of the mean batch response, the dosemeter shall be recalibrated before use.

5.9.1.8 The dosemeter reader should be calibrated before determining the dosemeter element correction factors.

5.10 PROCESSING

5.10.1 Each dosemeter shall be clearly labelled and identifiable so that the processing equipment applies the valid correction factor to each element.

5.10.2 Whilst awaiting to be processed, dosemeters shall be stored in a suitably low dose environment where the background is measured, and precautions shall be taken to ensure that the dosemeters are kept free from dust, grease and other harmful agents.

5.10.3 Processing equipment shall be suitably situated in a clean environment, which should be appropriately controlled with respect to temperature and humidity.

5.10.4 The dosemeter reader shall possess the following features:

5.10.4.1 accurately reproducible positioning of the dosemeter elements within the reader.

5.10.4.2 an accurately reproducible heating cycle.

5.10.4.3 stabilization against voltage change.

5.10.4.4 a method of checking and adjusting reader sensitivity.

5.10.4.5 instrument fault indicators and interlocks to prevent corruption and/or loss of information due to changes in system parameters.

5.10.4.6 a measurement and read-out system capable of indicating unambiguously absorbed dose within the range 0.1 mGy to 10 Gy.

5.10.4.7 anti-tamper devices to prevent unauthorised interference with system parameters.

5.11 DOSE EVALUATION

5.11.1 Dosemeters shall not be used for personnel dosimetry until the approval for operation has been received by the relevant regulator.

5.11.2 Dosemeters shall not be used for dose evaluation until the appropriate tests have been completed and the dosemeter element and reader calibration factors have been determined.

5.11.3 All measurements shall be recorded against the dosemeter number or code, which shall be clearly identified at the time of measurement.

5.11.4 Dose conversion factors listed in Appendix A and Appendix B to convert dosemeter response to dose equivalent, shall be implemented.

5.11.5 The assessment of shallow dose equivalent due to beta radiation shall be based on the response of dosemeter elements to beta radiation as determined by calibration against known beta radiation sources.

5.12 PERIODIC OPERATIONAL QUALITY CONTROL CHECKS

5.12.1 Annual operational quality control checks

5.12.1.1 On an annual basis, ± three months, the following shall be performed:

a. A batch homogeneity test shall be performed on all dosemeters. This test should include the verification of the element correction factors.

b. A repeatability test shall be performed on a representative sample of 200 dosemeters.

c. A stability of stored information test shall be performed (for a thirty-day storage period only) on a representative sample of 150 dosemeters.

d. A dose evaluation test shall be conducted with Eskom dosemeters irradiated by the CSIR. The dosemeters shall be irradiated to at least 2 known doses, one below 10 mSv and one above 20 mSv, to demonstrate system linearity. The variation of the test should not exceed ± 15 %.

5.12.2 Six-monthly operational quality control checks

5.12.2.1 On a six-monthly basis, ± one month, the following shall be performed:

a. The dosemeter reader shall be calibrated. In addition, this shall also be performed after instrument repair or whenever the reader calibration is questionable.

b. The cross-over point between the photon and frequency counting regions shall be determined.

5.12.3 Quarterly operational quality control checks

5.12.3.1 On a quarterly basis, ± one month, the following shall be performed:

a. A glow curve analysis shall be performed to check that the heating regime parameters are set to obtain optimum heating for all phosphors. In addition, this shall be performed whenever the reader is calibrated.

b. The Performance Index shall be performed in order to monitor any long-term variations in the response characteristics of the system.

5.12.4 Monthly operational quality control checks

5.12.4.1 On a monthly basis, the following shall be performed:

a. Prior to read-out of the personnel dosemeters, quality control dosemeters shall be processed with respect to accuracy. Should the relevant mean element response fall outside ± 15 %, the reading of dosemeters shall not commence until the reader has been rechecked and/or recalibrated if necessary. If the standard deviations of variation of the quality control dosemeters are greater than 5 %, the defective dosemeters shall be removed from service, or replaced.

b. If for any reason the performance of an individual dosemeter, or group of dosemeters are suspect, because of, for example, spurious readings when the exposure to an individual dosemeter is known to be zero, or because of damage incurred during wearing; the dosemeter(s) in question shall be selected for tests with respect to detection threshold, linearity, element precision and accuracy or the dosemeter(s) shall be taken out of service.

5.13 NOTIFICATIONS, RECORDS AND REPORTS

5.13.1 Dosimetry records shall be maintained in accordance with the requirements prescribed by the relevant regulator.

5.13.2 The results of all tests and quality control checks relating to the dosemeters, shall be documented.

5.13.3 Any changes to the dosemeter reader parameters shall be documented.

6. ACCEPTANCE:

This following people were informed of the request submitted to the National Nuclear Regulator (NNR) via letter K-28414-E and the NNR response via letter k28414N relating to implementation of administrative changes to this document.

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7. REVISIONS

Date	Rev.	Compiler	Remarks
March 2022	1	M Maree	Administrative changes implemented in accordance with letter k28414N dated, 22 March 2022.
December 2019	0B	M Maree	NNR approval via letter k26060N dated 6 December 2019 for extension of review date from October 2019 to May 2020.
September 2018	0A	M Maree	NNR approval via letter k24608N dated, 4 September 2018 for implementation of administrative changes.
March 2012	0	M Maree	NNR approval via letter k20275N dated, 12 March 2012 for implementation of Radiation Protection Standards.

8. DEVELOPMENT TEAM

This document has been developed by Marc Maree.

9. ACKNOWLEDGEMENTS

- E Flanagan
- K Featherstone
- MV Moduka

10. APPENDICES

A: Conversion factors for mono-energetic photons for computing dose equivalent from exposure in free

B: Conversion factors for x-rays for computing dose equivalent from exposure

APPENDIX A: CONVERSION FACTORS FOR MONO-ENERGETIC PHOTONS FOR COMPUTING DOSE EQUIVALENT FROM EXPOSURE IN FREE AIR

1 Rem = 10^{-2} Sv; 1R = 2.58 x 10^{-4} C.kg^{-1}

Photon Energy (keV)	**Conversion Factor [Sv.R^{-1}] to Dose Equivalent in the ICRU Sphere at a Depth of:**		
	1.0 cm [deep]	**0.3 cm [eye]**	**0.007 cm [shallow]**
15	0.28E-2	0.67E-2	0.90E-2
20	0.58E-2	0.79E-2	0.94E-2
30	1.00E-2	1.07E-2	1.11E-2
40	1.28E-2	1.29E-2	1.34E-2
50	1.46E-2	1.46E-2	1.50E-2
60	1.47E-2	1.47E-2	1.52E-2
70	1.45E-2	1.45E-2	1.50E-2
80	1.43E-2	1.43E-2	1.48E-2
90	1.41E-2	1.41E-2	1.45E-2
100	1.39E-2	1.39E-2	1.43E-2
110	1.37E-2	1.37E-2	1.40E-2
120	1.35E-2	1.35E-2	1.36E-2
130	1.33E-2	1.33E-2	1.34E-2
140	1.32E-2	1.32E-2	1.32E-2
150	1.30E-2	1.30E-2	1.30E-2
662	1.03E-2	1.03E-2	1.03E-2

APPENDIX B: CONVERSION FACTORS FOR X-RAYS FOR COMPUTING DOSE EQUIVALENT FROM EXPOSURE

The inherent filtration for the bremsstrahlung spectra produced at constant potential of 30 - 75 keV is 1.0 mm Be; that for the higher energies is 1.5 mm Al.

1 Rem = 10^{-2} Sv; 1R = 2.58 x 10^{-4} C.Kg^{-1}.

Constant Potential		Added Filter	Bremsstrahlung Technique			Conversion Factor [Sv.R^{-1}] to	
kV$_C$P (Mm)	Al	Cu mm	Half Value Layer Al mm	Homogeneity Coefficient [1st Al HVL] [2nd Al HVL]	Average Energy keV	Deep Dose Equivalent	Shallow Dose Equivalent
30	0.5	—	0.36	0.64	20	0.40E-2	0.92E-2
50	1.0	—	1.02	0.66	29	0.72E-2	1.02E-2
75	1.5	—	1.86	0.63	39	0.95E-2	1.14E-2
60	2.50	—	2.79	0.79	36	0.98E-2	1.14E-2
100	3.50	—	5.03	0.73	51	1.20E-2	1.30E-2
150	3.49	0.25	10.25	0.89	70	1.38E-2	1.43E-2