5. Dosimetry

The objective of dosimetry is to provide an accurate estimation of maximum and minimum irradiation doses given during the fruit flies pupae sterilisation process.

There are different reasons for performing dosimetry depending on the process. For example, there are ‘regulated processes’ such as food irradiation and sterilisation of health care products, where it is a legal requirement to perform dosimetry. In other cases, like plastic-insulation modification in electrical wires, the product quality and the economy of the process seem to be the driving force. In some other cases, it helps to scale up a process from the research level to the industrial level. Nearly all of these requirements apply to the case of Sterile Insect Technique (SIT) projects. Species targeted by SIT programmes are typically major pests affecting agriculture or human health, so the assurance that insects have been properly irradiated is of crucial importance to guaranty the efficiency of the SIT. This is achieved through standardized dosimetry, the key elements of which are accurate and reliable dose measurements. The principal role of dosimetry is in establishing the required minimum dose and also ensuring that correct dose is delivered to each insect container.

Selection of a suitable dosimetry system depends on several considerations, including dose range of interest, ease of measurement, the expertise available, environmental factors that can be important at the location of use, cost and uncertainty that is consistent with the process. Considering these factors, a radiochromic film dosimetry system seems to be the most suitable for SIT programme. These film dosimeters (generally 20-100 µm thick) change colour on irradiation, hence they are called ‘radiochromic’. The colour change that depends upon the level of absorbed dose is measured by a spectrophotometer at a selected wavelength or a simpler instrument, namely a photometer (with a fixed wavelength). There are several such systems, and Gafchromic® dosimetry system is selected based on the specific requirements of the SIT programme. This system offers SIT practitioners and their clients with a relatively simple, low cost and accurate means of assessing absorbed dose. The dosimeter is a small (about 1x1 cm square), thin (±100 micron) film which changes colour under radiation. Relevant dosimetry procedures as well as various components of this dosimetry system are described in the document ‘Gafchromic® Dosimetry System for SIT: standard operating procedure’ (FAO/IAEA 2001)[4]. The quality of dosimetry and hence the success of the sterilisation process depends on rigorously following this SOP. It is recommended that this document be closely followed for dosimetry. It also has examples of all the data forms necessary for dosimetry.

There is also an accompanying spreadsheet in Microsoft Excel format containing all necessary forms, with formulae to do the pertinent calculations automatically (the file contains no macros). Instructions are included in a separate document for the use of the spreadsheet. The spreadsheet and the instructions are available from the Insect Pest Control Section (www.iaea.org/programmes/nafa/d4/public/d4_pbl_5_2.html).

Even though this dosimetry system can be used for various types of radiation, including electrons, the procedures described here is limited to gamma radiation emitted by either ^{60}Co or ^{137}Cs.

The remaining sections describe some of the salient points for the following procedures for establishing and using the Gafchromic® dosimetry system for measurement of dose:

- Procedure for setting up and using Gafchromic® dosimetry system.
- Procedure for establishing traceability to a national/international standard.
- Procedure for establishing the calibration relationship for the dosimetry system.
- Procedure for determination of uncertainty in the measured dose value using the dosimetry system.

5.1. Dosimetry System

The Gafchromic® dosimetry system consists of:

- Gafchomic® film dosimeters.
- Radiachromic® reader plus accessories (see **Figure 18**).
- Procedure for its use.

The procedure for using the dosimetry system and the characteristics of the components are described here. More general information on radiochromic

[4] This document is referred to several times in this chapter. For convenience, it is referred as ‘the SOP’ henceforth.

film dosimetry system is available from references listed under 5.5 RELEVANT LITERATURE.

Gafchromic® Film Dosimeters (HD-810)[5]

a) ***Description:***

The film is about 0.1 mm thick, and it is almost colourless and transparent before irradiation. It turns blue practically instantaneously upon exposure to ionising radiation. However, the optical density (OD) of the film increases (the blue colour deepens) slightly with time after exposure. Thus, an irradiated film is read about 24 to 30 hours after irradiation. Also, the OD of the irradiated dosimeter film (for the same dose) depends slightly on the temperature of the dosimeter during irradiation as well as while its OD is read.

b) ***Handling:***

For reliable analysis, it is essential that the central portion of the film through which the analysing light passes is kept clean. Thus, the film should be held with a pair of tweezers (preferably with fine points) so as not to leave any fingerprints on the film, and touching only the edges of the film. It is preferable to wear thin polythene or latex (surgical) gloves for this activity. The film dosimeter is purchased as a large sheet (20 cm x 25 cm), and thus, as needed, it may be cut into small dosimeters of size about 0.9 cm x 0.9 cm, since the reader can accept films of this size only. After cutting, use a small paper envelope to store each film dosimeter, and remove it only for OD measurement. It is recommended to irradiate the dosimeter in the envelope to keep the dosimeter free of any dust or other contamination. Light, especially UV can induce colour change in the film simulating radiation dose. Hence, the films should not be exposed to sunlight, and the exposure to room lights (especially fluorescent lights) be minimised. The remaining sheet should be stored in its envelope when not in use. Also, it should not be stored in the same room with the irradiator for a long time.

c) ***Background-OD:***

Since only the radiation-induces colour change is related to dose, it is important to measure the OD of an un-irradiated film, also called 'background-OD'. This value must be determined for each lot of dosimeters following this procedure. Prepare ten dosimeters (9 mm x 9 mm) from the dosimeter sheet. Measure the OD of each dosimeter and calculate the mean value; this is background-OD. This is applied to all dosimeters of that lot. If the lot lasts longer than 6 months, the un-irradiated film may develop colour and therefore this procedure should be repeated to update the value of background-OD.

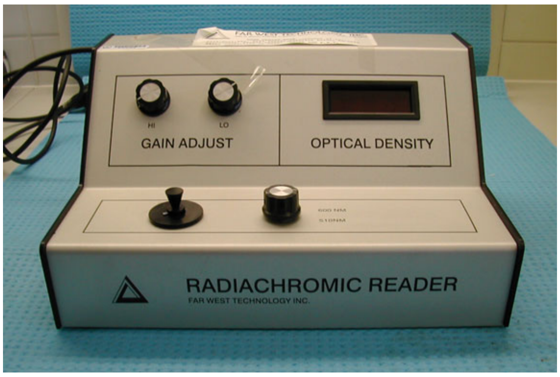

Figure 18: Radiachromic® reader

Radiachromic® Reader[6]

a) ***Description:***

The Radiachromic® reader, FWT-92 is a photometric instrument for the read-out of radiochromic dosimetry films, such as Gafchromic®. It displays digitally the OD value of the film being read. It has an option of selecting the wavelength of the analysing light, either 510 or 600 nm; the late should be used for SIT application.

Note: Operators are encouraged to read carefully the entire Operations Manual of the reader provided by the manufacturer before using the reader. As the Manual was developed for different film, namely FWT-60, there may be minor differences.

b) ***Set-up:***

For optimum operation, the reader should be placed in the laboratory at a location that is dust-free, away from direct sunlight and any air-draft, and where the temperature is relatively constant throughout the year. The absorbance scale of the reader should be periodically (daily when the reader is in use) checked against neutral density filters, which must have traceability to a national standard.

c) ***Adjustment of the absorption scale (HI/LO check):***

It is essential for the correct functioning of the reader that the absorption scale is adjusted regularly. For the high end of the scale, lift the dosimeter holder slightly (1-2 mm) from its well, rotate it through about 45°, and then release it. The 'HI' knob should then be adjusted to *just* display

[5] Supplied by International Specialty Products (ISP), New Jersey, U.S.A. Gafchromic® is a registered trade mark.

[6] Supplied by Far West Technology, Inc., California, U.S.A. Radiachromic® is a registered trademark.

9999 (and not 0.999), approaching from low numbers like 3. This sets infinite OD or 0% transmission. For the low end of the scale, lift the holder again from its well slightly and rotate it back to its normal position and then release it. Now the 'LO' knob should be adjusted *just* to read 0.000, approaching from non-zero numbers. This sets 0 (zero) OD or 100% transmission. (Note: If the low value cannot be set, the lamp may be too dim or burnt out and needs replacement.) Repeat the above steps until both readings are correct, that is, no further adjustments are needed.

d) ***Maintenance of the absorption scale:***

Use the set of three neutral density (ND) filters[7] to check the consistent operation of the reader (absorption scale). Each filter should be placed in the well of the reader replacing the dosimeter holder, and its OD value measured. The nominal values are approximately: 0.3 (for the filter marked yellow), 0.6 (green) and 1.1 (blue). The actual values will vary slightly from reader to reader. Initially, these values should be measured during the calibration of the dosimetry system. Later, these values should be checked at least once a day when the reader is in use. Best time is before starting measurements of the dosimeter films. Note: The OD values should be the same (the last digit may change by 1 or 2) as that during calibration of the dosimetry system. Different values indicate a potential problem with the reader. Refer to the Operations Manual of the reader for troubleshooting.

Procedure

a) ***Routine procedure for optical density (OD) measurement:***

The procedure listed below should be followed routinely to measure optical density (OD) of a film dosimeter.

- Check that the reader is set up as specified.
- Check that the selected wavelength is 600 nm.
- Before any OD measurements, perform the HI/LO check and repeat it every 30 minutes during the measurement session.
- Measure the OD of the three ND filters at least once a day, preferably before starting the measurements with the dosimeter films. Compare these OD values with those measured during the calibration of the dosimetry system. Different values indicate problem with the reader.
- Measure the OD of the dosimeter.
- Always place the dosimeter holder in its well in the reader when not in use.

5.2. Establishing Traceability

General

A system of calibration should exist within each country to ensure that all dose measurements can be related to the national standard, and through that to the international measurement system, through an unbroken chain of comparisons. Such a chain is known as *traceability chain.* Without such traceability, the measurement does not have much validity. The most common method of establishing traceability is to determine the dose rate value at a reference point in the radiation field by means of transfer-standard dosimeters supplied and analysed by a standards laboratory. It is important that the irradiation geometry and irradiation conditions at this reference point are reproducible. It is important that these transfer-standard dosimeters are from a recognised or accredited laboratory or a national laboratory. There are several laboratories that provide this service, for example, NIST in USA, NPL in UK, RISO in Denmark.

IAEA Dose Assurance Service

The International Atomic Energy Agency also offers such a dosimetry service (International Dose Assurance Service, IDAS) through its Dosimetry and Medical Radiation Physics Section. Request for participating in this service may be sent to Head, Dosimetry and Medical Radiation Physics Section, IAEA. The transfer-standard dosimeter used by the IAEA is alanine. After receiving the IDAS dosimeter set from the IAEA, it should be irradiated at a reference point in the radiation field following the procedure given below. After irradiation, dosimeter set should be returned to the IAEA for analyses along with the IDAS data sheets. The IAEA will then analyse the dosimeters and issue a certificate stating the dose received by the dosimeters and the uncertainty in that value.

Reference Irradiation Conditions

The placement of the IDAS dosimeter set at a fixed reference point should be consistent to achieve reproducible results. This can be conveniently achieved by using a specially designed dosimeter holder, a support stand and arranging a set of reference marks in the irradiation chamber so that the holder can be placed in exactly the same position each time.

A self-contained irradiator, such as Nordion and Sheppard Gammacell and Husman irradiator, consists of several radioactive pencils generally

[7] Supplied by Far West Technology, Inc., California, U.S.A.

arranged in a cylindrical array. The sample or a dosimeter to be irradiated is located (stationary or rotated) in the middle of the cylindrical irradiation chamber where the dose rate is high and relatively uniform. For this type of irradiator, the most suitable dosimeter holder is an open cylinder (like a cup). The SOP describes an example of such a dosimeter holder which has the inside diameter of about 27 mm (just large enough to accommodate three dosimeters, each being about 12 mm in diameter). It should be made of any polymeric material, such as PMMA. The dosimeter holder should be located in the irradiation chamber so that the dosimeters are at the centre of the radiation field, where the dose rate is most uniform. Also, some method should be available to position this holder always at the same location. The SOP also describes the design of a support stand suitable for Nordion Gammacell 220 for this purpose.

A panoramic irradiator consists of several radioactive pencils arranged in a plane or as a single rod. For routine operation, the sample is either located stationary in front of the source and rotated, or it passes by or around the source. Even though the sample (for example, pupae canister) may be moving past the radiation source for routine irradiation, it may be necessary in some cases that the dosimeters are *stationary* for the dose-rate measurement and also for calibration irradiations (see 5.3 CALIBRATION OF GAFCHROMIC® DOSIMETRY SYSTEM). For such irradiators, the dosimeter holder is flat and is placed in such a way that the flat surface is perpendicular to the radiation beam. An example of such a dosimeter holder is also given in the SOP. It should be located at a reference point that is at approximately the same distance from the source as the sample is during routine irradiation. Also, some method should be available to position this holder always at the same location in the radiation field.

Irradiation

The IDAS alanine dosimeter is a long rod: 12 mm in diameter and 50 mm long[8]. An IDAS set consists of three such dosimeters in a black pouch that should be irradiated together, preferably within the pouch. For a cylindrical dosimeter holder, all three IDAS dosimeters may be positioned in a triangular fashion within the pouch (without opening it), and placed snugly into the holder. For a flat holder, the IDAS pouch needs to be cut opened and the three dosimeters placed in the three holes of the holder. The dosimeter holder should then be carefully placed at the reference point in the radiation field. The selected dose value is a compromise between several requirements:

- Alanine dosimetry requires that the dose should be greater than 600 Gy.
- The dose should be large enough so that the transit dose[9] is negligible (i.e. < 0.5%). (see "Transit Dose" in 5.3 CALIBRATION OF GAFCHROMIC® DOSIMETRY SYSTEM).
- The dose should be as small as possible so that the temperature of the dosimeter does not change significantly during irradiation.

Optimum value for IDAS irradiation is discussed in the SOP for several irradiators. The irradiation time is then estimated from an approximate value of dose rare at the reference point. Ensure that the timer used for time measurement is calibrated with traceability. See manufacturer's documentation on how to check timer accuracy. The temperature of the dosimeter should be controlled or monitored during irradiation. If possible, control the dosimeter temperature during irradiation at 25°C; this is the temperature at which alanine dosimeters are calibrated by the IAEA. If the control of the dosimeter is not possible, the dosimeter temperature must be measured or estimated *just* before irradiation (minimum temperature) and *immediately* after irradiation (maximum temperature) by temporarily introducing a standard thermometer inside the dosimeter holder next to the dosimeters (without damaging the black pouch).

Dose Rate at the Reference Point

The IAEA Dosimetry Laboratory will analyse the dosimeters and send the results to the participant as an IDAS certificate. It contains information regarding dose received by the IDAS dosimeters and the uncertainty in this value. Using this value of the dose and the time of irradiation, dose rate at the irradiation position can be calculated. Here it is assumed that the transit dose is insignificant compared to the delivered dose. Dose rate is generally expressed in units of Gy/s, Gy/min or kGy/hour. Note that this value is valid for the specific irradiation conditions at the reference point and for the day of irradiation. However, it is independent of the irradiation temperature.

Frequency

The dose rate should be measured every 3 to 4 years by using transfer-standard dosimeters from a standards laboratory, such as IAEA Dosimetry Laboratory. It may be necessary to do it earlier if any relevant part of the irradiation system is altered,

[8] IAEA alanine dosimeter consists of an alanine rod (30-mm long and 3-mm in diameter) which is housed inside a polystyrene capsule which has outside diameter of 12 mm and is 50 mm long.

[9] Transit dose is the dose received by the dosimeter when the source or the dosimeter is moving.

such as replenishment of the source, or modification to movement mechanism or irradiation set up that can affect the dose rate.

5.3. Calibration of Gafchromic® Dosimetry System

Calibration is the relationship between the absorbed dose and the resulting response of the dosimeter (in this case, it is the change in optical density, OD) for specific irradiation conditions (such as dosimeter temperature during irradiation). A dosimetry system must be calibrated before it can be used to measure dose.

Calibration procedure for a dosimetry system consists of:

- Irradiating several dosimeters at the reference point (where dose rate is accurately known) at specified dose levels.
- Measuring the OD of the irradiated dosimeters with the reader and determining the response for each dosimeter.
- Establishing a relationship between response and dose.

These steps are discussed thereafter.

Irradiation

It is essential that the Gafchromic® dosimeters are irradiated at the same reference point where the dose rate was determined with IDAS dosimeters, and with the same irradiation geometry and conditions. Thus, the *same* dosimeter holder should be used. Since films are physically different than alanine dosimeters, a special film holder is necessary. An example of such a dosimeter holder is given in the SOP. It consists of a solid rod of PMMA of 12-mm diameter and 50-mm long. A long cut is made along the length for inserting a dosimeter film-strip 9 mm x 50 mm. Three such film holders (with the Gafchromic® films) are then placed in the dosimeter holder (cylindrical or flat depending on the type of irradiator). The dosimeter holder then should be placed exactly at the same location as it was during IDAS irradiation.

Several dose values should be selected within the useful dose range; exact values depend on the type of insect. For fruit flies, calibration irradiation should be performed at 6 dose levels nominally set at: 50, 80, 120, 160, 200 and 240 Gy. The corresponding irradiation times can be calculated from the known dose rate (from IDAS irradiation) on the day of irradiation[10]. The dosimeters are then irradiated for these times or some convenient times close to these values may be selected. As mentioned earlier, it is essential to control the dosimeter temperature during irradiation, or to monitor it continuously, or to measure the minimum temperature (*just* before starting irradiation) and the maximum temperature (*immediately* after irradiation). If possible, all irradiations should be carried out at approximately the same temperature.

Calculate the effective value of the dosimeter temperature, T_{eff} by averaging the measured values for each irradiation. If all the irradiations were not performed at the same temperature, calculate the calibration temperature, T_{cal} as the mean of all the T_{eff} values determined above. This T_{cal} value is later used for correcting the measured OD values.

Response Determination

After irradiation, it is be necessary to cut the irradiated film-strip into three dosimeters of size 9 mm x 9 mm, so as to fit them in the reader holder. Wait for about 24 to 30 hours before measuring the OD of these dosimeters using the procedure given in "Routine Procedure for Optical Density (OD) Measurement" in 5.1 DOSIMETRY SYSTEM. There are several dosimeters which were irradiated at the same dose. Calculate the mean and standard deviation for the OD values for these dosimeters for each dose. The coefficient of variation (CV) at each dose may be calculated by:

$$CV(\%) = (\text{standard deviation} / \text{mean}) \times 100$$

The value of CV should not be more than 2% for each dose.

The measured OD value needs to be corrected for the background-OD and for dosimeter temperature during irradiation. Thus, response is calculated as:

$$\text{Response} = (\text{Measured OD} - \text{Background OD})\ (1 - 0.0073 \times \Delta T),$$

where, 0.0073 $°C^{-1}$ = temperature coefficient for Gafchromic® dosimeter (ISP 1999), and:

$$\Delta T\ (°C) = T_{eff} - T_{cal}.$$

[10] The dose-rate value on the day of irradiation should be calculated based on the dose-rate value measured with the transfer-standard dosimeters and the time interval since then. This calculation requires the half-life value of the radioactive source; this value for cobalt-60 is 5.271 years (Unterweger *et al.* 1992) and for Cesium-137 is 30.07 years (Tuli 1994).

Transit Dose

Transit dose is defined as the dose a sample or dosimeter receives while either the source or the sample/dosimeter is moving. It is essential to estimate the value of transit dose for the irradiator being used for SIT programme. There are two reasons for this: (1) IDAS dose should be such that the transit dose is insignificant in comparison, and (2) for calibration of Gafchromic® dosimetry system, the correct value of dose received by the dosimeters must be known.

If the transit dose is less that 0.5% of the minimum irradiation dose (for example, for fruit flies the minimum dose for calibration is 50 Gy; and 0.5% is 0.25 Gy), then the transit dose may be completely ignored. Considering this, transit dose may be ignored for Gammacells with dose rate less than about 4 Gy/min. For irradiators with higher dose rate, detailed procedure is given in the SOP for the estimation of transit dose.

This value of transit dose should be added to each of the 6 nominal dose values (namely, 50, 80, 240 Gy) to determine 'actual dose' value received by the dosimeters. Thus,

actual dose = (dose rate on the day of irradiation) x (irradiation time) + transit dose.

Calibration Relationship

The objective here is to determine the relationship (generally, mathematical) between the dosimeter response (y-axis) and the actual value of dose received by the dosimeter (x-axis). This is achieved most conveniently by regression analyses; the SOP uses this procedure and the required spreadsheet is available from the Insect Pest Control Section.

For the case of fruit flies, this relationship is almost linear, but quadratic fit may be better. The calibration relationships may be described as:

Linear function: Response = a + b (Dose)

Quadratic function: Response = c + d (Dose) + e $(\text{Dose})^2$

The selection between the two can be made by observing the distribution of the percentage residuals[11] for the two cases following the procedure given in the SOP. This calibration relationship is valid for the specific lot of dosimeters for one year, and for the temperature employed for the irradiations, T_{cal}.

[11] For each response value, residual is calculated as follows: Residual(%) = 100 x $(D_{cal} - D_{actual}) / D_{actual}$, where D_{actual} is the actual value of dose and D_{cal} is the calculated value of dose for the corresponding response value using the calibration relationship.

Frequency

The dosimetry system should be calibrated every year, or sooner if any part of the dosimetry system is changed, such as new lot of dosimeters or repairs to the Radiachromic® reader. [Note: a lamp change in the reader does not require re-calibration]

Use of the Calibration Relationship

To measure dose at a point, follow the procedure given below.

Irradiation:

1. Place one 9 mm x 9 mm dosimeter (3 dosimeters are preferable) from the calibrated lot at each point of interest. Use a small envelope for the dosimeter(s) and write the relevant identification and information on the envelope. More than one dosimeter may be placed in one envelope.

2. Irradiate the sample (with the dosimeters in the envelope).

3. Estimate the effective temperature (T_{eff}) of the dosimeter during irradiation (see "Uncertainty in the dose value arising from uncertainty in the irradiation temperature during dose measurement, u_{temp-i}" in 5.4 UNCERTAINTY).

OD measurement: [Note: These measurements are made about 24-30 hours after irradiation]

4. Turn the reader on and wait for at least 30 minutes with the dosimeter holder in place in the reader for its temperature to stabilize.

5. Follow the procedure in "Routine Procedure for Optical Density (OD) Measurement" in 5.1 DOSIMETRY SYSTEM to measure the OD of the dosimeter(s).

6. Determine response for each dosimeter following the expression given in "Response Determination" (this section).

Dose determination:

7. Determine dose using the value of the response and the calibration relationship determined in "Routine Procedure for Optical Density (OD) Measurement" in 5.1 DOSIMETRY SYSTEM.

5.4. Uncertainty

Uncertainty reflects the degree of accuracy in the measured value, and thus it is essential to evaluate it. First, the sources of uncertainty should be identified, and their effects minimized as much as possible; and then the remaining ones should be evaluated. This is most easily done by dividing and sub-dividing the procedures for calibration and use of the dosimetry system into smallest activities, and then assessing what uncertainties are likely to be associated with each of them. The uncertainty associated with the dose measurement can then be calculated by combining the individual components together.

For Gafchromic® dosimetry system, the total uncertainty in the measured dose value consists of the following components [Note: all these components are in %]:

Uncertainty in the Dose Value due to Uncertainty in the Dose-rate Value, u_{dr}

Uncertainty in the dose-rate value at the reference point is transferred to the uncertainty in the measured dose value. This value is available in the IDAS certificate (see "Dose Rate at the Reference Point" in 5.2 ESTABLISHING TRACEABILITY), or from the national laboratory that provided the transfer-standard dosimeters.

Uncertainty in the Dose Value Arising from the Calibration Relationship, u_{fit}

This represents the uncertainty arising from the fitting procedure and is based on the values of the residuals (see "Calibration Relationship" in this section). Detailed procedure for calculating this value is described in the SOP. In brief,

$$u_{fit} = \{\Sigma(\text{Residual}(\%))^2 / n\}^{1/2},$$

where, n is the total number of data points in the calibration relationship, and the summation to be carried over all these n values.

Uncertainty in the Dose Value Arising from Non-homogeneity in the Dosimeter Lot, u_{lot}

Response to dose of all dosimeters in a lot is not exactly the same. This non-homogeneity adds to the uncertainty in the measured dose. This value is determined by irradiating several (say, 10) dosimeters selected randomly from the lot. They should be irradiated to the same dose under identical conditions and then analysed in a similar way. They should be irradiated *together* (if possible) at about 100 Gy. Calculate the mean and standard deviation of the response values, and determine coefficient of variation CV(%). The uncertainty component u_{lot} = CV(%). However, if n dosimeters are used at one location to measure dose, the uncertainty in the mean value is reduced by $\sqrt{n}$. Thus, u_{lot} for n dosimeters = CV(%)/$\sqrt{n}$.

Uncertainty in the Dose Value Arising from Uncertainty in the Irradiation Temperature during Dose Measurement, u_{temp-i}

As discussed in "Response Determination" (this section), the measured OD value is corrected for irradiation temperature if it is different than that during calibration. However, if the irradiation temperature is not known accurately, this procedure introduces uncertainty in the correction applied. Assuming that the effective dosimeter temperature, T_{eff} during irradiation is known to be between T_{min} and T_{max}, $u_{temp-i} = 0.73\{(T_{max} - T_{min})/2\}/\sqrt{6}$. The factor of $\sqrt{6}$ is based on the assumption that the effective temperature has triangular probability distribution within the two limits (ISO 1993). Note: if, for example, $(T_{max} - T_{min})$ = 10°C, u_{temp-i} = 1.5%.

Uncertainty in the Dose Value Arising from Uncertainty in the Dosimeter Temperature during OD Read-out, u_{temp-r}

The measured OD value depends on the dosimeter temperature during read-out. If this value is different than its value during calibration of the dosimetry system, a correction needs to be applied to the measured OD value. The dosimeter temperature during read-out depends, to some extent, on the ambient temperature surrounding the reader, and hence the need to ensure that the laboratory temperature is as uniform as possible through out the year. The measured OD can be corrected if the dosimeter temperature during read-out is known, however it is difficult to measure this. Thus, if it is assumed that the dosimeter temperature during read-out is within ±5°C of its value during calibration, $u_{temp-r} = 0.7 \times 5/\sqrt{3}$ (~ 2%) where, 0.7% $°C^{-1}$ is the read-out temperature coefficient as estimated in the IAEA Laboratory. The factor of $\sqrt{3}$ is based on the assumption that the dosimeter temperature has rectangular probability distribution within the two limits (ISO 1993).

Total Uncertainty in the Measured Dose Value, u_{total}

The total uncertainty in the measured dose value, u_{total} (%) is then given by adding these components in quadrature:

$$u_{total} = (u_{dr}^2 + u_{fit}^2 + u_{lot}^2 + u_{temp-i}^2 + u_{temp-r}^2)^{1/2}$$

All these values of u are for 1 standard deviation (σ). However, to imply a higher level of confidence that the 'true' value lays within the reported range, u_{total} should be multiplied by a coverage factor k. As a general practice, k = 2 is used. Thus, one can state with about 95% confidence that the 'true' dose value lays within $D_{measured} \pm 2u_{total}$.

This value has impact on the dose selected for processing the insects. The target dose that the process should be set for is then calculated as:

$$\text{Target dose} = \text{Minimum dose} + (2 \times u_{total})$$

5.5. Relevant Literature

American Society for Testing and Materials (ASTM), 2001a. Standard Practice for Use of a Radiochromic Film Dosimetry System. Designation: E 1275-98. Annual book of ASTM standards. Vol. 12.02, 714-718.

American Society for Testing and Materials (ASTM), 2001b. Standard Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing. Designation: E 1261-00. Annual book of ASTM standards. Vol. 12.02, 696-713.

American Society for Testing and Materials (ASTM), 2001c. Standard Guide for Estimating Uncertainties in Dosimetry for Radiation Processing. Designation: E 1707-95. Annual book of ASTM standards. Vol. 12.02, 886-905.

American Society for Testing and Materials (ASTM), 2001d. Standard Terminology Relating to Radiation Measurements and Dosimetry. Designation: ASTM E 170-99. Annual book of ASTM standards. Vol. 12.02, 1-8.

American Society for Testing and Materials (ASTM), 2001e. Standard Practice for Using the Fricke Reference Standard Dosimetry System. Designation: ASTM E 1026-95. Annual book of ASTM standards. Vol. 12.02, 538-544.

American Society for Testing and Materials (ASTM), 2001f. Standard Guide for Use of Radiation-Sensitive Indicators. Designation: E 1539-98. Annual book of ASTM standards. Vol. 12.02, 797-798.

American Society for Testing and Materials (ASTM), 2001g. Standard Guide for Dosimetry for Irradiation of Insects for Sterile Release Programs. Designation: E 1940-98. Annual book of ASTM standards. Vol. 12.02, 1036-1046.

FAO/IAEA, 2001. Gafchromic® Dosimetry System for SIT: Standard Operating Procedure, D4.10.16, International Atomic Energy Agency, Vienna, Austria.

International Organization for Standardization (ISO), 1993. Guide to the expression of uncertainty in measurement, Geneva, Switzerland.

International Organization for Standardization (ISO), 1995. Sterilization of health care products – Requirements for validation and routine control – Radiation sterilization, ISO 11137, Geneva, Switzerland.

ISO/ASTM, 2002. Standard guide for irradiation of insects for sterile release programs. E-51940. 11pp.

International Specialty Products, 1999. ISP Data Sheet, NJ, USA.

Sharpe, P.H.G. 1999. Calibration and traceability in high dose dosimetry, Invited paper at International symposium on Techniques for high dose dosimetry in industry, agriculture and medicine, TECDOC-1070, 281-288. IAEA. Vienna, Austria.

Tuli, J.K. 1994. Nuclear data sheets update for A = 137, Nuclear data sheets, Vol. 72, 136.

Unterweger, M.P., D.D. Hoppes and F.J. Shima. 1992. New and revised half-life measurement results. Nuclear Instruments and Methods, Physics A, Vol. 312, 349-352.