

***WORKING MATERIAL***

***Gafchromic® Dosimetry System for SIT***

Standard Operating Procedure

Produced for the FAO/IAEA Co-ordinated Research Project  
“Quality Assurance of Mass Produced and Released Fruit Flies  
for SIT Programmes” (D4.10.16)

1.0b



# Gafchromic® Dosimetry System for SIT

## Table of Contents

Preface .....	1
1. Introduction .....	2
2. Dosimetry system .....	3
2.1. General .....	3
2.2. Radiachromic® reader .....	3
2.3. Gafchromic® dosimeter film (HD-810) .....	6
3. Establishing traceability .....	9
3.1. General .....	9
3.2. Reference radiation field .....	9
3.3. Reference irradiation conditions .....	12
3.4. Transfer standard dosimetry system .....	14
3.5. Dose rate .....	15
3.6. Frequency .....	15
4. Characterisation of Gafchromic® dosimetry system .....	15
4.1. Calibration .....	15
4.2. Lot homogeneity .....	21
4.3. Uncertainty .....	21
4.4. Characteristics of the current lot of dosimeters .....	22
5. Dose distribution measurement (Dose mapping) .....	22
5.1. Objective .....	22
5.2. Research application .....	23
5.3. Commercial application .....	23
5.4. Reference location .....	23
6. Process control .....	23
6.1. General .....	23
6.2. Routine dosimetry .....	24
6.3. Process parameter monitoring .....	24
6.4. Radiation-sensitive indicators .....	24
7. Documentation .....	24
Appendix A - Modifications to the 'Operations Manual' of the Radiachromic® reader .....	25
Appendix B - Recommended data forms for documentation .....	26
Annex I .....	41
Annex II .....	42



## **Preface**

There are different reasons for performing dosimetry depending on the process. For example, there are 'regulated processes' such as food irradiation and sterilisation of medical products, where it is a legal requirement to perform dosimetry. In other cases, like plastic modification in electrical wires, the requirement is the product quality. 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 by standardized dosimetry that insects have been properly irradiated is of crucial importance to agricultural growers, agricultural regulators, public health officials and the public.

Selection of a suitable dosimetry system depends on several considerations, including dose range of interest, the precision and 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, Gafchromic® dosimetry 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 (1x1 cm square), thin (~100 micron) film which changes colour under radiation. This colour change, which depends on the absorbed dose, is then measured by a photometric reader.

This document describes the components of the Gafchromic® dosimetry system, the procedure for its characterisation, and its application to process validation and process control. Like almost all dosimetry systems, the performance of Gafchromic® system is affected by environmental factors, such as temperature and time of analysis. The quality of dosimetry and hence the success of the sterilisation process thus depends on rigorously following this Standard Operating Procedure (SOP).

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

This Standard Operating Procedure was produced by Dr. Kishor Mehta under IAEA contract 2000CL9124 with assistance from staff of the Insect Pest Control Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

## **1. Introduction**

This document is basically divided into three parts:

- description of the Gafchromic® dosimetry system,
- characterization of the dosimetry system and establishing its traceability to the international measurement system, and
- use of this dosimetry system for SIT projects.

The first part (consisting of Section 2) describes the two main components of the dosimetry system, namely the GAFCHROMIC® film dosimeters and the Radiachromic® reader. It includes information about handling the film, its absorption behaviour and influence quantities (environmental parameters) that affect the performance of these film dosimeters. Also, it describes the procedure for set up and for routine optimal operation of the reader.

The second part (Sections 3 and 4) describes the procedures for characterization of the dosimetry system, and for establishing traceability to the international measurement system. Characterisation includes:

- calibration of the dosimetry system,
- determination of the lot homogeneity, and
- determination of uncertainty in the measured dose.

Traceability is established through determination of the dose rate, using transfer standard dosimeters from the IAEA Dosimetry Laboratory, at a fixed reference point in the radiation field. This fixed point will vary depending on the type of irradiator in use at a given location. This reference point should be fully defined so that Gafchromic® dosimeters can be placed at this same location for calibration irradiation. If there is more than one irradiator in the laboratory, choose one convenient to place the dosimeters and where the temperature can be either controlled or measured more easily. Once the dosimetry system is calibrated by irradiating Gafchromic® dosimeters at this reference point, it is ready to be used anywhere with almost any type of irradiator.

The third part (Sections 5 and 6) describes the use of this calibrated dosimetry system in any irradiator that the CRP participants may use for irradiating fruit flies or other insects either for research or commercial purposes. It reviews the procedures for carrying out dose mapping for process validation, as well as process control.

To assist the readers and add to its transparency, this SOP also includes:

- all the data forms necessary for the procedures described in this document (in Appendix B),
- some typical data for the characterisation of the dosimetry system (these are based on actual data generated at the IAEA Seibersdorf Laboratory), and
- several figures and photographs of equipment and activities.

There is also an accompanying spreadsheet in Microsoft Excel 95 format containing all the forms, with formulae to do the necessary calculations automatically (the file contains no macros). Instructions are included in a separate document for the use of the spreadsheet.

## 2. Dosimetry system

### 2.1. General

The dosimetry system consists of GAFCHROMIC® film dosimeters, Radiachromic® reader and accessories.

### 2.2. Radiachromic® reader<sup>1</sup>

The Radiachromic® reader FWT-92 is a photometric instrument for the read-out of radiochromic dosimetry films, such as Gafchromic®. It can read the optical density (OD) of the film for two wavelengths, 510 and 600 nm. *However, only 600 nm shall be used for Gafchromic® films.* The operation of the reader is simple and is described in Section 3 of the 'Operations Manual'. However, because this manual was developed for FWT films and not for Gafchromic® film dosimeters, there are some statements/procedures in the manual that are not relevant to Gafchromic® dosimetry system. Because of this, the main steps for the operation of the reader that are specific to Gafchromic® dosimetry system are given below.

Note: Operators are encouraged to read the entire Operations Manual carefully before using the reader. The recommended changes to the text of this manual, mainly due to the different dosimeter film, are given in Appendix A.

#### 2.2.1. Set up

##### 1. Locate the reader

- in a clean and dust-free environment,
- in a room where the temperature is between 20 and 35°C (preferably even more uniform) throughout the year (because the OD value is affected by the dosimeter temperature during read-out, also see Section 2.3.5),
- in a location where there is no direct sunlight on it,
- so that there is no air draft (such as that due to an air-conditioner or an open window).

##### 2. Check that the power/voltage supply is consistent with local requirements.



(a)

(b)

*Photograph 1: Two positions of the reader dosimeter holder during the HI/LO check: (a) the holder blocks the light beam completely thus providing infinite value of OD, notice that the holder is slightly raised in this position, and (b) the holder lets the beam pass completely unhindered thus providing zero value of OD.*

<sup>1</sup> Supplied by Far West Technology, Inc., California, U.S.A. Radiachromic is a registered trademark.

3. Turn the reader on. It takes about *30 minutes* to stabilise. Make sure that the dosimeter holder is in place in the reader. Note: This procedure allows the holder temperature to attain a stable value. The OD value of the Gafchromic® film depends on the temperature during its measurement (see Section 2.3.5).
4. Adjustment of the absorption scale (HI/LO check):
  - a) High end of the scale – Select the wavelength setting at 600 nm. Lift the dosimeter holder slightly from its well, rotate it through about 45°, and then release it (see Photograph 1a). This position of the holder blocks the light path of the analysing beam completely and simulates an infinite OD. Adjust the ‘HI’ knob to *just* display 9999 (and not 0.999), approaching from low numbers like 3. This sets infinite OD or 0% transmission.
  - b) Low end of the scale – Now lift the holder again from its well slightly and rotate it back to its normal position and then release it (see Photograph 1b). Adjust the ‘LO’ knob *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.
  - c) Repeat the above steps until both readings are correct, that is, no further adjustments are needed.

#### *2.2.2. Routine operation for OD measurement*

1. Ensure that the reader is set up according to Section 2.2.1.
2. Ensure that the selected wavelength is 600 nm.
3. Before any OD measurements, perform the HI/LO check and repeat it every 30 minutes during the measurement session.
4. Measure OD of the three neutral density (ND) filters<sup>2</sup> at least once a day when the reader is in use, preferably before starting the OD measurements on the dosimeters (Section 2.2.3).
5. Remove the dosimeter holder from its well, place the dosimeter in the holder and replace the holder in the well. For more details on handling the dosimeter, see Section 2.3.6.
6. Wait for about 30 seconds (no longer) and read the OD value. Note: The last digit in the OD value may increase by 3 or 4 in the first 10 seconds. After this, there should not be any change in the OD value. Record the reading when there has been no change for 10 seconds or more. If the reading continues to change after more than 30 seconds the reader temperature has not yet stabilized. Return the holder to the reader (without the dosimeter) and leave for a further 30 minutes for the temperature to stabilize.
7. Remove the dosimeter from the holder. Note: Use forceps to remove the dosimeter from the holder, taking care to grasp it by an edge. Do not grasp the dosimeter near its centre as this could scratch the film and affect the reading. See 2.3.6 Handling.
8. Always place the dosimeter holder in its well in the reader when not in use. This helps maintain the holder at a constant temperature, and also keeps dust out of the well and out of the light path.

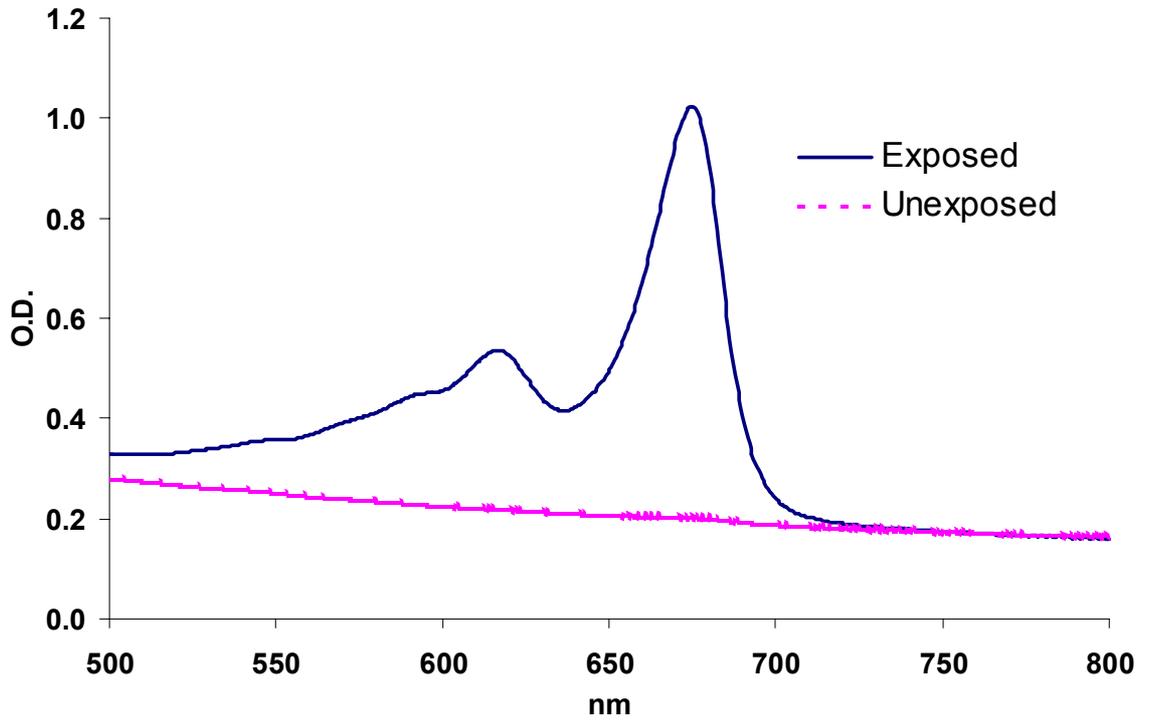
#### *2.2.3. Maintenance of the absorption scale*

Use the set of three ND filters to check the consistent operation of the reader (absorption scale). This information shall be documented using the prescribed Form-SIT-1 (Appendix B).

---

<sup>2</sup> Supplied by Far West Technology, Inc., California, U.S.A.

(a)



(b)

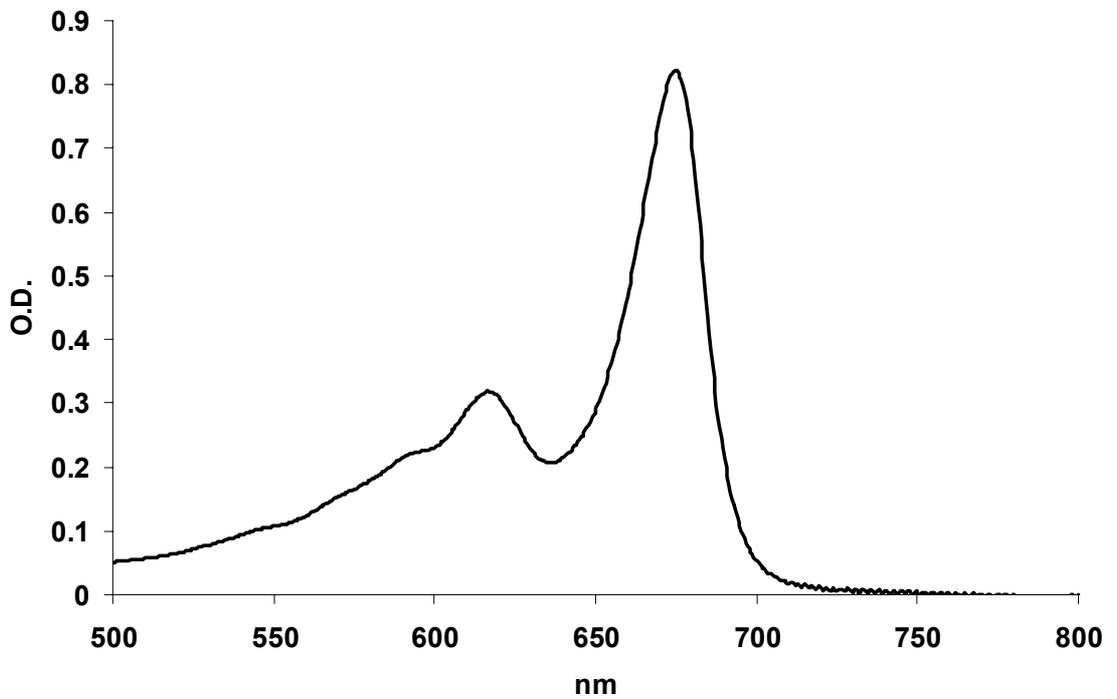


Fig. 1. Absorption spectra for Gafchromic® dosimeter material: (a) exposed and unexposed; (b) difference between the two spectra.

1. Initially this should be done during the calibration of the dosimetry system (Section 4.1.2). Place each filter in the well of the reader replacing the dosimeter holder, and measure the OD. 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.
2. Subsequently, this check shall be carried out at least once a day when the reader is in use, preferably before the OD-measurement session begins. 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 trouble shooting.

### 2.3. Gafchromic® dosimeter film (HD-810)<sup>3</sup>

#### 2.3.1. *Description*

The following tables give the structure and composition of the film (D. Lewis, I.S.P., personal communication).

Material	Thickness (microns)	Density (g/cm <sup>3</sup> )
polyester film base	97	1.35
active layer	6.5	1.08
gelatine	0.75	1.2

Composition (atom %)			
C	H	O	N
45.50	36.40	18.20	0.00
31.50	56.00	5.00	7.50
23	53	8	16

#### 2.3.2. *Absorption spectrum*

The absorption spectra for the Gafchromic® dosimeter material for the wavelength region of relevance (500 – 800 nm) are given in Figs 1a and 1b (D. Lewis, I.S.P., personal communication). Figure 1a shows the spectra for unirradiated as well as irradiated film. Figure 1b shows the difference spectrum between these two. The wavelength to be used for the present application is 600 nm.

#### 2.3.3. *Response*

The film is almost colourless and transparent before irradiation, and it turns blue almost instantaneously upon exposure to ionizing radiation. However, the OD of the film increases (the blue colour deepens) slightly with time after exposure; the rate of change decreases with time. After about 24 hours, the OD value stabilises to a value approximately 15 – 20% over its initial value (measured within a few minutes after exposure). This behaviour is illustrated in Fig. 2 for dose of about 100 Gy (data from Seibersdorf laboratories). The intensity of the blue colour (OD) is a function of the radiation dose.

#### 2.3.4. *UV light*

There are no extreme measures to be taken to protect the dosimeter film against UV light. However, do not expose the films to the sunlight, and keep exposure to room lights (especially fluorescent lights) to the minimum required to handle the films and

---

<sup>3</sup> Supplied by International Specialty Products (ISP), New Jersey, U.S.A. Gafchromic is a registered trade mark

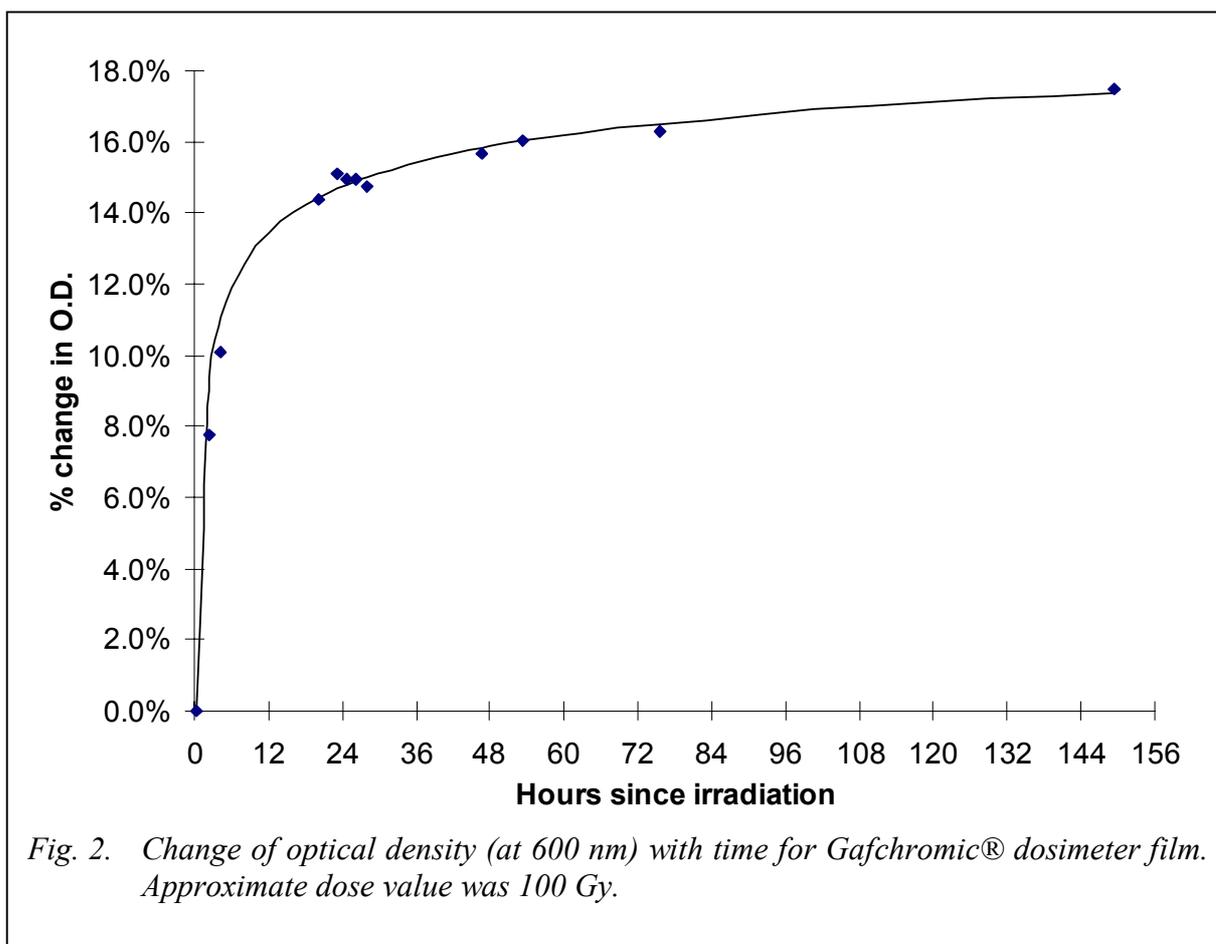


Fig. 2. Change of optical density (at 600 nm) with time for Gafchromic® dosimeter film. Approximate dose value was 100 Gy.

for the measurements. Store the large film sheet in its envelope in a dark place when not handling it.

### 2.3.5. Temperature dependence

The OD of the irradiated dosimeter film (for the same dose) depends on the temperature of the dosimeter during irradiation as well as while its OD is read.

The irradiation temperature coefficient for Gafchromic® dosimeters is 0.73%/°C (Data Sheet - Gafchromic® Dosimetry Medium, I.S.P.); that is, the OD value increases by 0.73% for 1°C increase in the dosimeter temperature during irradiation (for the same dose). Because of this, either the temperature of the dosimeter during irradiation should be controlled or should be measured/estimated and its effect corrected for (more on this later in Section 4.1).

The dependence of the OD on the dosimeter temperature during its read-out was determined by Li *et al.*, Radiation Physics and Chemistry **57** (2000) 103-113. However, such effects quite often vary from lot to lot. Some limited experiments carried out in the IAEA Laboratory indicate that the read-out temperature coefficient is about 0.7%/°C for the current lot of dosimeters in the room-temperature range of 20-25°C. Because of this, it is essential that the ambient room temperature where the reader is located stays fairly constant through out the year.

### 2.3.6. Handling

Handle the film with a pair of tweezers (preferably with fine points) so as not to leave any finger-prints on the film (see Photograph 2). Finger-prints, scratches on the film surface, dirt or dust can affect the light absorption of the film. Also, the tweezers tips should touch only the edges of the film, away from the centre portion where the analysing light passes through it.

The dosimeter film is purchased as a sheet of about 20 cm x 25 cm. However, the size that the dosimeter holder of the reader can accommodate

is about 1 cm x 1 cm. The sheet needs to be cut in this size prior to taking readings. The best way is to use a sharp utility knife or a single-edged razor blade and a plastic ruler. It is convenient to choose the correct size by placing the film sheet on grid paper while cutting it. Wear thin polythene or latex (surgical) gloves for this activity to avoid leaving finger-prints on the film (see Photograph 3). For ease of inserting the film in the dosimeter holder, cut the film slightly smaller, about 0.9 cm x 0.9 cm. Store the remaining sheet in its envelope when not in use. Do not store it for a long time in the same room with the irradiator.

Use a small paper envelope to store each film dosimeter. Place the dosimeter in it and remove it only for OD measurement. It is recommended that you irradiate the dosimeter in the envelope when it is placed in the container with the pupae to keep the dosimeter free of any dust or other contamination. Also, record relevant identification/ information on the envelope, such as dosimeter identification, irradiation location, exposure time, conditions and date of irradiation. Do not write on the envelope with the film inside, as this may mark the film.



*Photograph 2: A pair of fine pointed tweezers is being used to hold the dosimeter film along one edge whilst placing it inside the reader dosimeter holder. Notice that the tweezers touch only the edge of the film to avoid scratching the centre of the film where the OD reading will be taken.*



*Photograph 3: A sharp utility knife, a plastic ruler and a grid paper under the film help to cut it in desirable lengths conveniently. Apply a slight pressure on the ruler with the other hand to keep the film from moving during cutting. It is very essential that a pair of thin surgical gloves is used during this activity to avoid fingerprints.*

### 2.3.7. Background OD

Measure the OD value of the unirradiated film for each lot of dosimeters. Note: One or two 20 cmx25 cm sheets that each CRP participant has received from the IAEA constitute a lot for each participant. The identification number for the first lot is: 7726-09. Cut 10 dosimeters from the dosimeter sheet. Measure OD of each dosimeter following the procedure of Section 2.2.2, and record the values on Form-SIT-2 (Appendix B). Estimate the mean and the standard deviation for these 10 values. This mean value, taken as OD(bkgd), shall be applied to all dosimeters of the present lot (see Section 4.1.2). Enter this value and the date of measurement in Form-SIT-9 (Appendix B).

If the lot lasts longer than 6 months, this measurement should be repeated.

## 3. Establishing traceability

### 3.1. General

Traceability is an ability to demonstrate by means of an unbroken chain of comparisons, which is known as a *traceability chain*, that a measurement is in agreement within acceptable limits of uncertainty with comparable nationally or internationally recognised standards. This section describes the procedure for establishing traceability for the dose measurements made by the laboratory of each CRP participant using their Gafchromic® dosimetry system.

This is accomplished by determining the value of the dose rate at a fixed reference point in the radiation field of each laboratory. The dose rate is measured with transfer standard dosimeters supplied and analysed by the IAEA Dosimetry Laboratory which is traceable to a national standards laboratory. The Gafchromic® dosimetry system is then calibrated by irradiating the dosimeters at various dose levels at the same reference point.

### 3.2. Reference radiation field

Basically there are two types of irradiators that are used for SIT, either for research or for industrial irradiation. For both types, it is important that the dose is as uniform as possible at the reference point where the dose rate is to be established, and later where the Gafchromic® dosimeters are irradiated for calibration.

**Self-contained irradiators:** In this case, the radioactive source pencils or elements are generally arranged along the circumference of a cylinder and the sample to be irradiated is located within this cylindrical volume. For such a case, the sample/dosimeter receives radiation from all directions and thus the radiation field in the centre of this volume is quite uniform. Nordion or Sheppard Gammacell and Husman irradiators fall into this category. Gammacell has several <sup>60</sup>Co pencils and thus the radiation field is more symmetrical and uniform compared to that for the Husman irradiator which has source pencils only at three locations along the circumference. Figure 3 shows a typical dose-rate distribution in air in the irradiation chamber of a Nordion Gammacell-220.

**Panoramic irradiators:** The source generally consists of several radioactive pencils arranged in a plane or as a single rod. For routine irradiation, either the sample is located stationary in front of this source, or it passes by or around the source. For this type of irradiator, the sample receives radiation from one side at a time. The spatial uniformity of dose for a stationary sample may be improved by either

continuously rotating it during irradiation or turning it through 180° after half of the total irradiation time.

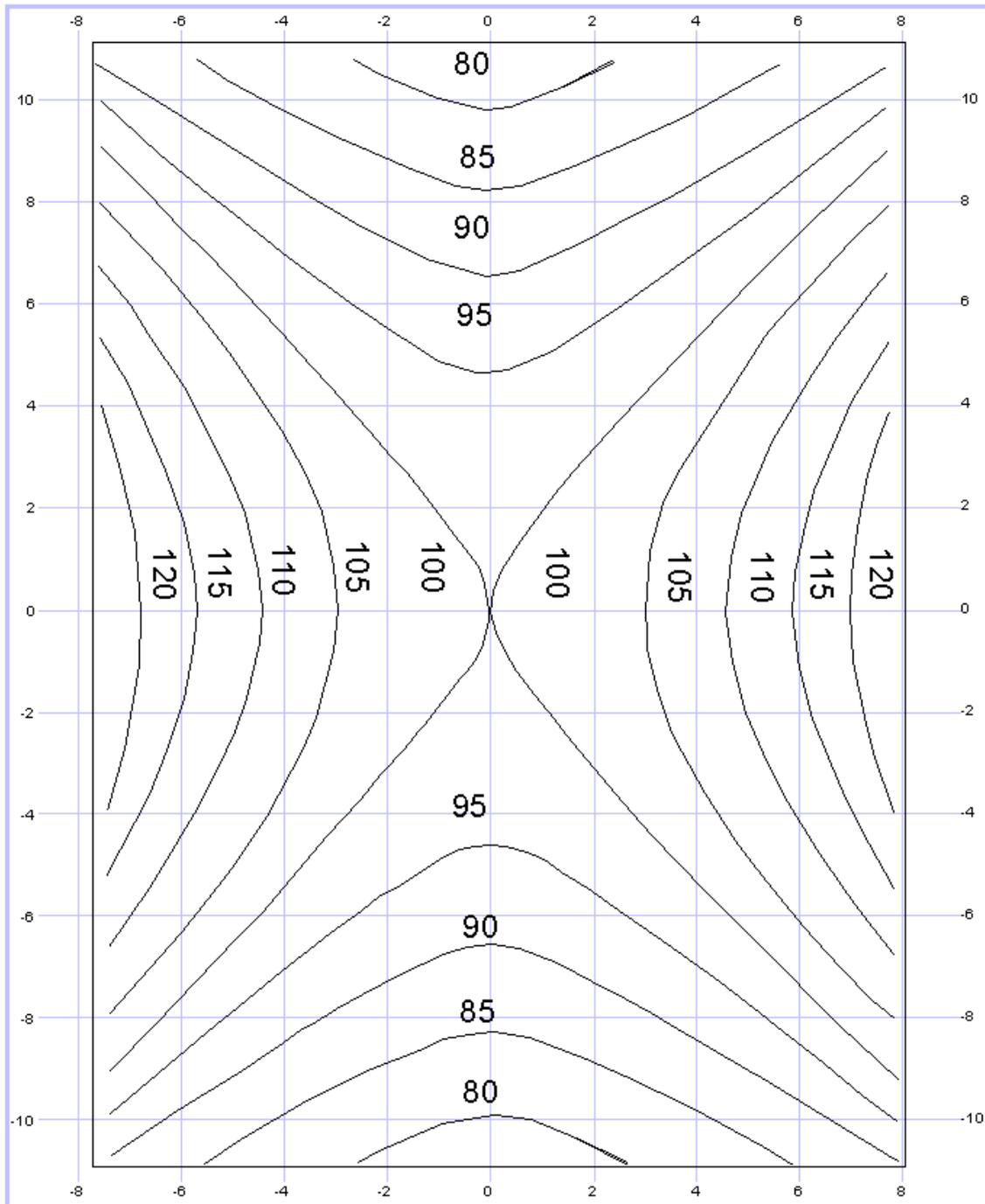


Fig. 3. Typical dose-rate distribution in the irradiation chamber of Nordion Gammacell-220. The values are normalised to 100 in the centre of the gamma field. Note that the field is most uniform in the centre. (Grid is at 2 cm intervals from the centre of the chamber). Redrawn from Nordion data.

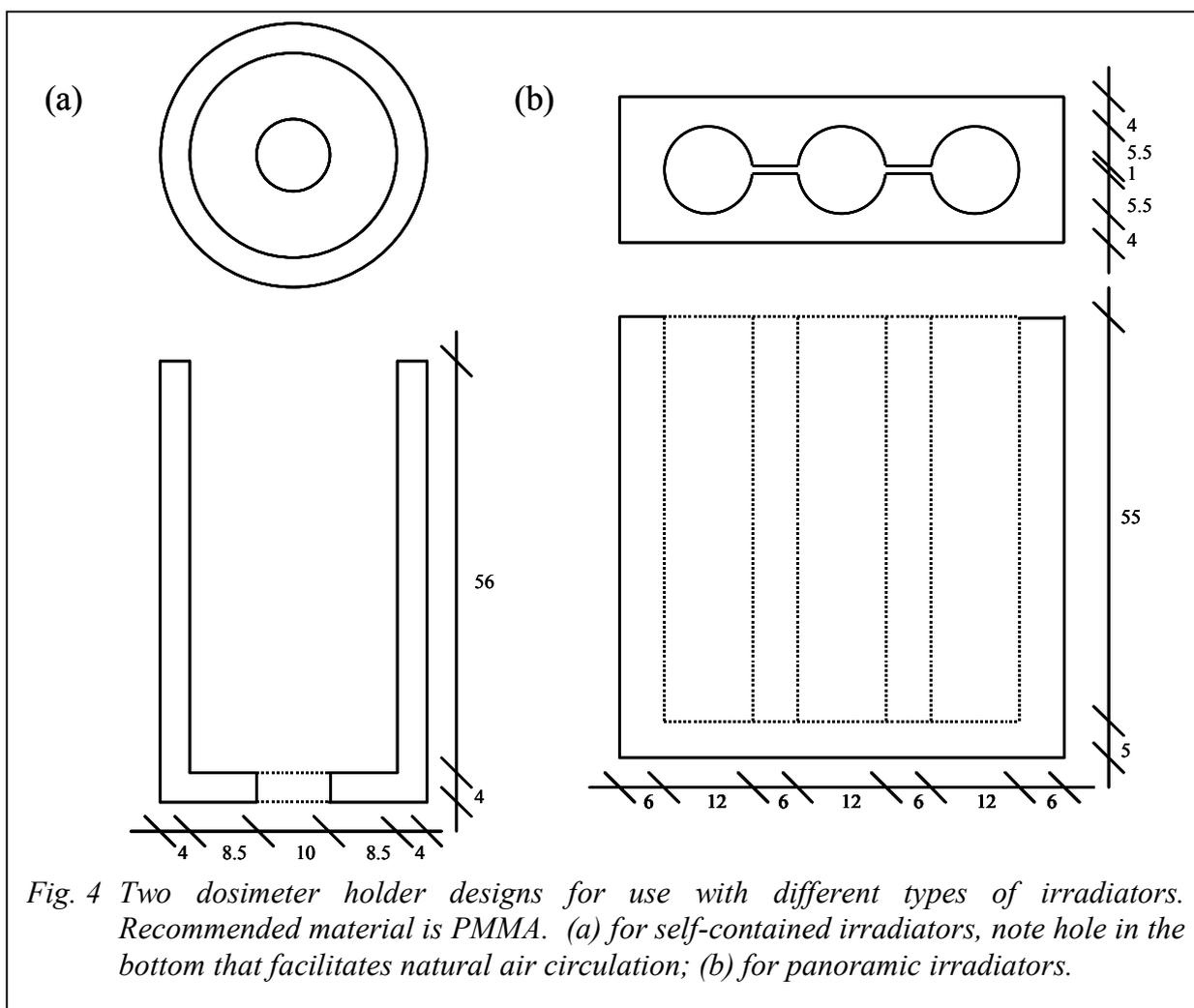
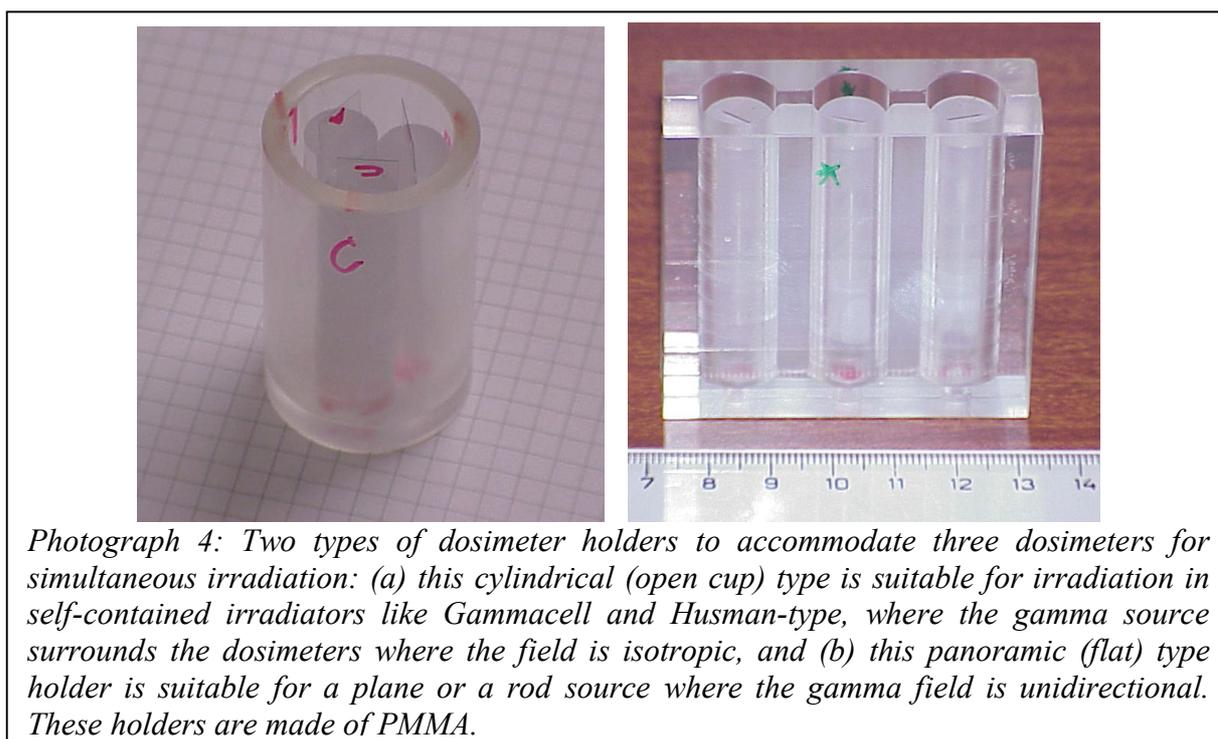


Fig. 4 Two dosimeter holder designs for use with different types of irradiators. Recommended material is PMMA. (a) for self-contained irradiators, note hole in the bottom that facilitates natural air circulation; (b) for panoramic irradiators.



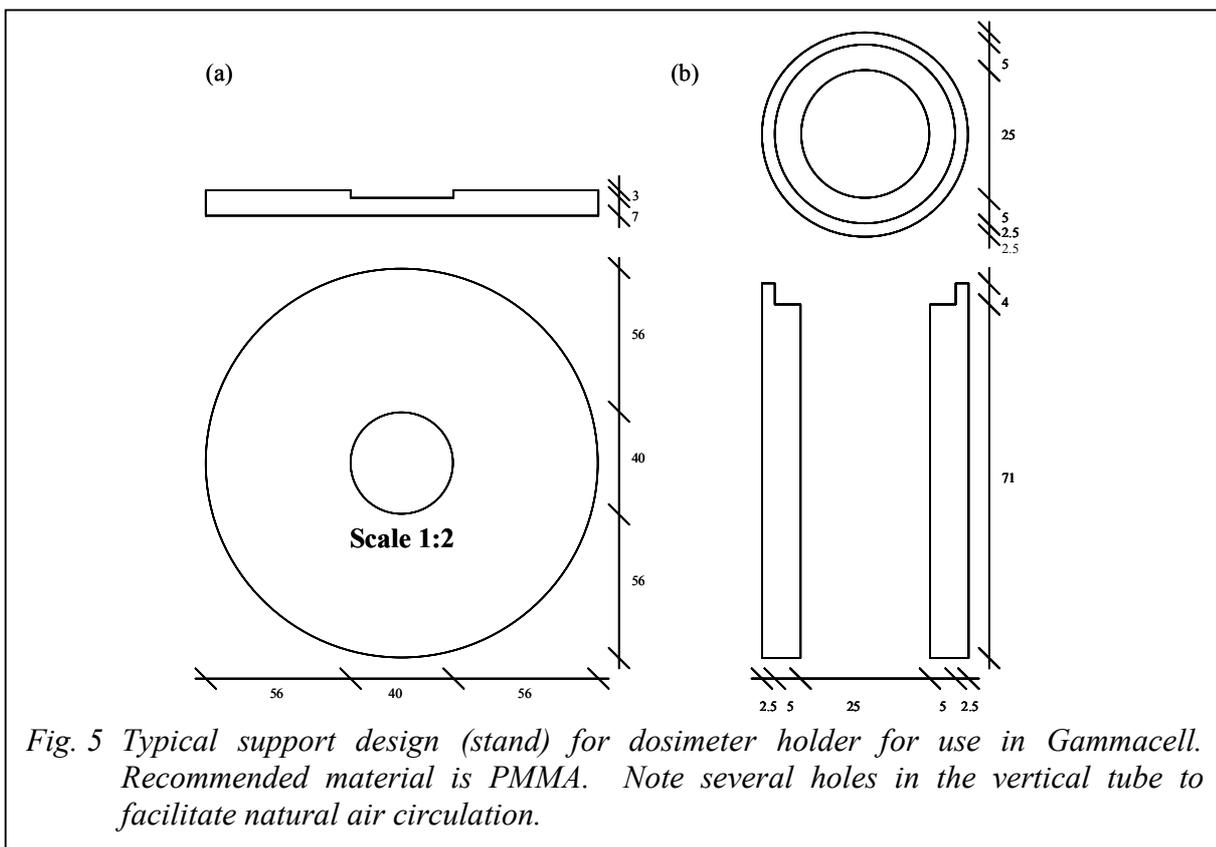
Photograph 4: Two types of dosimeter holders to accommodate three dosimeters for simultaneous irradiation: (a) this cylindrical (open cup) type is suitable for irradiation in self-contained irradiators like Gammacell and Husman-type, where the gamma source surrounds the dosimeters where the field is isotropic, and (b) this panoramic (flat) type holder is suitable for a plane or a rod source where the gamma field is unidirectional. These holders are made of PMMA.

### 3.3. Reference irradiation conditions

#### 3.3.1. *Irradiation geometry*

The placement of the dosimeters at a fixed reference point should be consistent to achieve reproducible results. This can be achieved by (i) using a specially designed dosimeter holder, and (ii) arranging a set of reference marks in the irradiator sample chamber so that the holder can be placed in exactly the same position each time.

Self-contained irradiators: Figure 4a shows a dosimeter holder designed specifically for this type of irradiator (also see Photograph 4a). It is made of PMMA (any polymeric material is acceptable) and is an open cylinder (like a cup) with the inside diameter (~ 26 mm) just large enough to accommodate three dosimeters, each being about 12 mm in diameter. The wall thickness (4 mm) of the holder is selected to provide the optimum amount of material for achieving electron equilibrium for  $^{60}\text{Co}$  gamma rays. This standard design is recommended for use in all Gammacell-220 irradiators. Such a holder can also be used for Husman irradiators containing  $^{137}\text{Cs}$  by modifying the design of the base to fit within the exposure chamber. For both types of irradiators, 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 (Fig. 3). Also, some method should be available to position this holder always at the same location in the reference field; Fig. 5 shows a standard support design for the Gammacell-220 (also see Photograph 5). For irradiation in a Gammacell-220, place this stand in the irradiation chamber and then place the dosimeter holder of Fig. 4a securely on top of this. This ensures that the dosimeters placed in the holder are always at the same location in the radiation field, and if the dimensions are correct the centre of the dosimeters is at the centre of the radiation field. Note: The centre of the dosimeters, for both alanine and Gafchromic® films, is about 20mm above the inside bottom of the dosimeter holder.





Photograph 5: A cylindrical dosimeter holder (as shown in Photograph 4a) is firmly placed on a PMMA stand for irradiation in a Gammacell. This stand consists of a circular base plate that just fits in the irradiation chamber of the Gammacell. In the centre of this plate is a tube on which the dosimeter holder is placed. The height of this tube should be such that, when the device is placed in the Gammacell, the centre of the dosimeters coincides with the geometric centre of the radiation field. A mark may be placed on the base plate so that it is always placed in the same orientation in the irradiation chamber of the Gammacell. Also, a mark may be placed on the cylindrical dosimeter holder for reproducible positioning. A similar device must be used for a Husman irradiator so that the dosimeters (in the cylindrical dosimeter holder) can be consistently placed at the same position in the gamma field.

Panoramic irradiators: Even though the sample (pupae container) 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 (Section 4.1). Figure 4b shows a dosimeter holder specifically designed for this type of source (also see Photograph 4b). Generally, it should be located at approximately the same distance from the source as the sample generally is during routine irradiation (to experience similar dose rate). As mentioned above (Section 3.2), the holder should be rotated continuously during irradiation. Alternatively, it should be turned through 180° around the vertical axis after half the irradiation time. In this case, care should be taken to position the holder at the same location after rotation.

### 3.3.2. Irradiation temperature

Because the response of nearly all dosimeters depends on the dosimeter temperature *during* irradiation, measure/estimate the dosimeter temperature during irradiation. Generally, the temperature should be determined within 2-3°C, and preferably it should be controlled.

### 3.4. Transfer standard dosimetry system

The International Atomic Energy Agency (IAEA) offers a dosimetry service (International Dose Assurance Service, IDAS) through its Dosimetry and Medical Radiation Physics Section. The scientific secretary of the CRP should request DMRP Section to issue dosimeter sets for the CRP members. He should collect the required number of dosimeter sets (one for each CRP member) from the DMRP Section and distribute them to the CRP members. The irradiated dosimeters should be returned to the scientific secretary who should pass them on to DMRP Section for analyses.

The IAEA transfer dosimetry system consists of alanine dosimeters and EPR spectrometer to measure the dosimeter response. The alanine dosimeter (alanine rod + polystyrene capsule) is 50 mm long and 12 mm in diameter. One dosimeter set consists of three such alanine dosimeters for irradiation, and one as a control (not to be irradiated). This dosimetry system, and thus the measurement made by it, is traceable to the Primary Standard Dosimetry Laboratory of U.K. (NPL).

Each CRP participant should irradiate the three dosimeters *together* (in the black pouch as it is received from the IAEA) at the reference point using the specific holder (Section 3.3.1) without removing the dosimeters from the black pouch. For use in the cylindrical dosimeter holder shown in Fig. 4a, position all three dosimeters in a triangular fashion within the pouch and place them snugly into the holder, such that the red arrow on the label is pointing up. The irradiation time should be such that the dose value is generally between 500 and 1000 Gy.

Note: This value should be adjusted for each laboratory depending on the dose rate, transit dose and the expected temperature rise. The objective would be to make the transit dose negligible (less than 0.5% of the dose given to the IDAS dosimeters) without too much (<5°) rise in the temperature of the dosimeter during irradiation (unless temperature is controlled).

Annex I gives the individual value for each CRP participant.

Ensure that the timer used for time measurement is calibrated with traceability. See manufacturer's documentation on how to check timer accuracy.

If possible, control the dosimeter temperature during irradiation at 25°C (which is the temperature at which the alanine dosimetry system is calibrated by the IAEA). Alternatively, measure the dosimeter temperature during irradiation. If an easy method (for example, thermocouples) for measuring the temperature during irradiation is not available, measure the temperature of the dosimeters *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). Record both of these temperature values and enter the information in the IDAS data sheet (which is sent along with the IDAS dosimeter set). If the dosimeter temperature was measured continuously, attach that information to the IDAS data sheet.

Use Form-SIT-3 for recording data for this procedure (Appendix B).

The IAEA Dosimetry Laboratory will analyse the dosimeters and relate the results (dose values) to the CRP scientific secretary who will then relate the results to the CRP members. The IDAS certificate should also contain information regarding uncertainty in the dose value. Enter this value as  $u_{df}$  in Form-SIT-9 (Appendix B).

3.5. Dose rate

Each laboratory then should calculate the dose rate from the IDAS dose value and the irradiation time (assuming that transit dose is negligible).

Dose rate = Dose / Irradiation time; the dose rate may be expressed in kGy/hour, Gy/min or Gy/s.

Record this value of dose rate in Form-SIT-3. This value is valid for the specific irradiation conditions employed and for the day of irradiation. However, it is independent of the irradiation temperature.

3.6. Frequency

The dose rate should be measured every three years, or sooner if any relevant part of the irradiation system is altered, such as replenishment of the source, or modification to movement mechanism or irradiation set up that can affect the dose rate.

4. **Characterisation of Gafchromic® dosimetry system**

Characterisation of a dosimetry system consists of:

- calibration of the dosimetry system,
- determination of the homogeneity of the dosimeter response for a lot, and
- determination of total uncertainty in the measured dose value.

Procedure for each of these is described below.

Use Form-SIT-9 to list the various characteristics of the current lot of dosimeters.

4.1. Calibration

Calibration of a dosimetry system consists of irradiating several dosimeters at

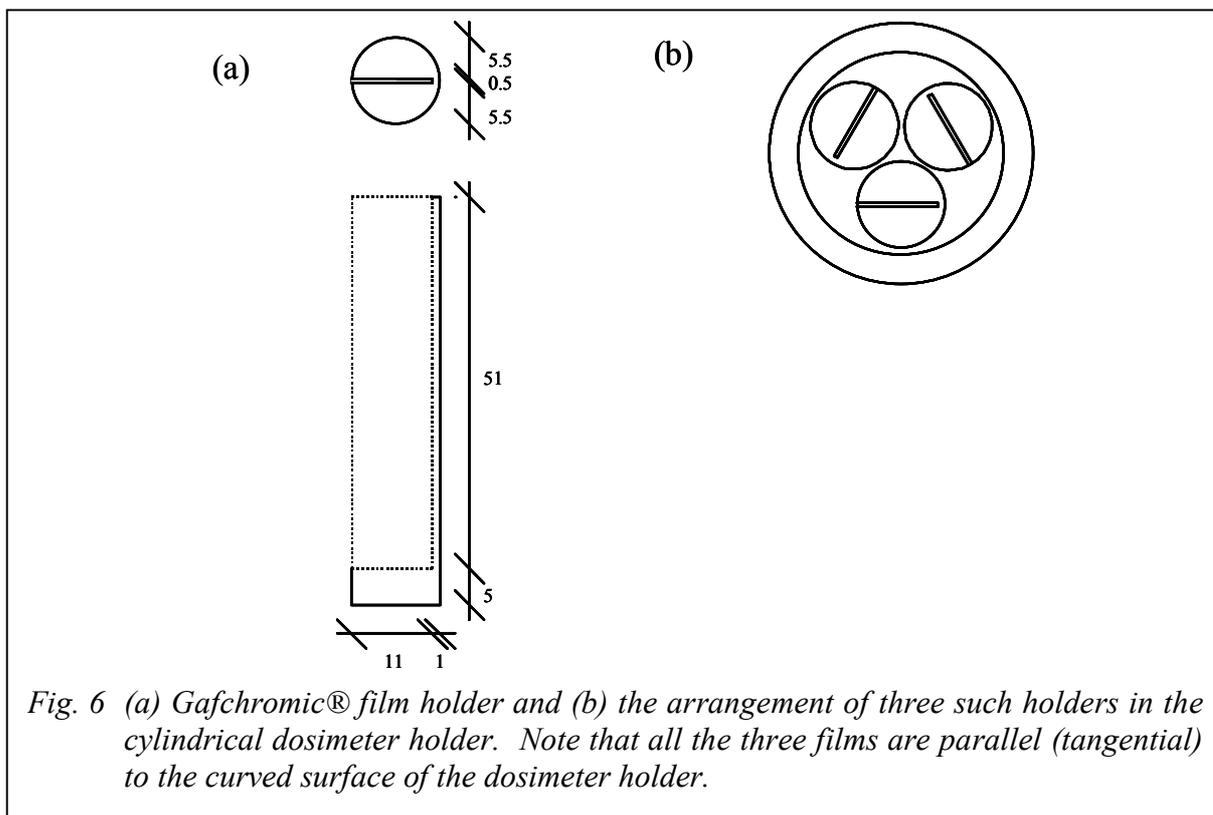


Fig. 6 (a) Gafchromic® film holder and (b) the arrangement of three such holders in the cylindrical dosimeter holder. Note that all the three films are parallel (tangential) to the curved surface of the dosimeter holder.

specified dose levels, measuring the OD and determining the response for each dosimeter, and establishing a relationship between response and dose. Each of these steps is discussed below.

#### 4.1.1. Irradiation

Irradiate Gafchromic® dosimeters at the same reference point where the dose rate was determined, and with the same irradiation geometry using the same dosimeter holder. Figure 6a shows a standard design of film holder that is compatible with the geometries of dosimeter holders of Figs 4a and 4b. There are three such cylindrical film holders; identify them by writing A, B or C at the bottom (uncut end) of the holders with a felt pen. Cut three film strips (5 cm x 1 cm) and identify them by writing A, B or C at one end of each film with a felt pen. Insert the film strip (holding it with a pair of tweezers at the marked end) in the slot in the PMMA cylindrical film holder. Then insert three such film holders in the dosimeter holder (either Fig. 4a or 4b) for simultaneous irradiation similar to three alanine dosimeters. Arrange these film holders so that each film is parallel to the wall of the dosimeter holder as shown in Fig. 6b (also see Photograph 6). To keep the film holders from rotating within the dosimeter holder, you may place a small piece(s) of paper between them. For a flat dosimeter holder, the film holders should be placed so that the films are parallel to the largest face of the dosimeter holder.



Photograph 6: Three film holders with Gafchromic® dosimeters are placed in a cylindrical holder for irradiation in a Gammacell. Note that each film holder is placed so that the film is parallel (tangential) to the curved surface of the dosimeter holder. For a flat dosimeter holder, the film holders should be placed so that the films are parallel to the longer face of the dosimeter holder.

For fruit flies, calibration irradiation should be performed at 6 dose levels nominally set at: 50, 80, 120, 160, 200 and 240 Gy. Calculate the corresponding irradiation times as:

Irradiation time = Dose / Dose rate (of today)

NOTE: The dose rate to be used here should be calculated from the most recent value when it was measured (Section 3.5) and correcting for radioactive decay from that day till 'today'.

It is calculated as: Dose rate (of today) = Dose rate (Section 3.5)  $e^{-\lambda\Delta t}$ , where,  $\Delta t$  = decay time (in days),  $\lambda(^{60}\text{Co}) = 3.5991 \times 10^{-4} \text{ d}^{-1}$  and  $\lambda(^{137}\text{Cs}) = 6.3097 \times 10^{-5} \text{ d}^{-1}$ . These decay constant values are based on half lives of 1925.5 days for  $^{60}\text{Co}$ , and 30.07 years for  $^{137}\text{Cs}$ .

Record the value of the dose rate (of today) and the irradiation times in Form-SIT-4A (Appendix B).

Measure the dosimeter temperature throughout irradiation (see Photograph 7). If this is not possible, measure the minimum temperature (*just* before starting irradiation) and the maximum temperature (*immediately* after irradiation) of the dosimeters (see Section 3.4 for details of how to measure these). Determine the effective dosimeter temperature, T(eff) for each irradiation:

for continuous measurements:  $T(\text{eff}) = \text{average of all measurement values}$ ,  
for before/after measurements:  $T(\text{eff}) = T(\text{minimum}) + 2/3 (\Delta T)$ ,  
where,  $\Delta T = T(\text{maximum}) - T(\text{minimum})$ .

If possible, control the temperature so that  $T(\text{eff})$  for all irradiations is within  $2^{\circ}\text{C}$ . Calculate the calibration temperature,  $T(\text{cal})$  as the average of the six  $T(\text{eff})$  values. This information is used later for correcting the measured response value for temperature effect. Record the temperature values in Form-SIT-4A (Appendix B).

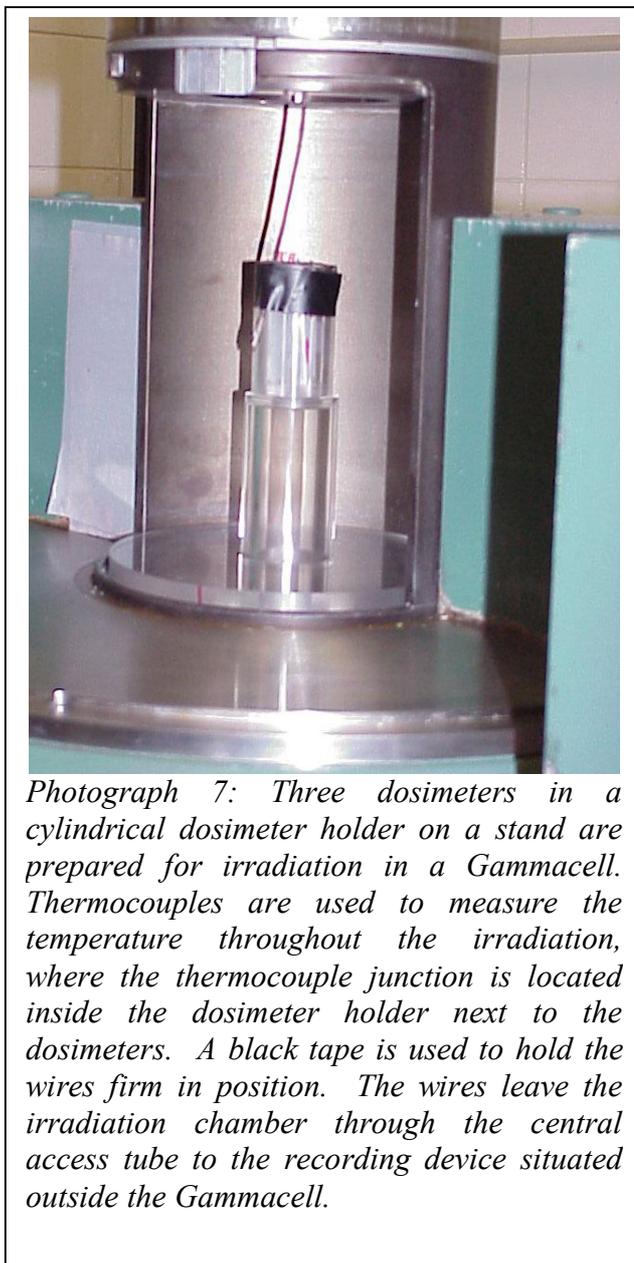
#### 4.1.2. Response determination

After irradiation, cut three pieces (about  $1\text{cm} \times 1\text{cm}$ ) from each strip starting from the unmarked end, so that each piece fits into the dosimeter holder of the Radiachromic® reader for OD measurement. Note that about 2 cm of film containing the identification mark is left over which is not used for OD measurement. Place each set (A, B, C), containing three  $1\text{cm} \times 1\text{cm}$  films and the left-over piece, in a separate envelope for safeguarding. Since the colour develops over some time, measure the OD of the dosimeters between 24 and 30 hours after irradiation (Section 2.3.3).

Check the high and low absorption scales every thirty minutes during the OD-measurement session, and adjust the 'HI' and 'LO' knobs if necessary (see Section 2.2.1).

Measure the OD of the three ND filters before starting the read-out of the dosimeters, and repeat after reading all the dosimeters. Record these values in Form-SIT-4B and Form-SIT-1 (Appendix B).

Measure the OD of each dosimeter film following the procedure given in Section 2.2.2. For each dosimeter set (A, B, and C), calculate the mean OD and the standard deviation for the three dosimeters, and record the values in Form-SIT-4B. Thus, for each dose level, there are three mean OD values.



Photograph 7: Three dosimeters in a cylindrical dosimeter holder on a stand are prepared for irradiation in a Gammacell. Thermocouples are used to measure the temperature throughout the irradiation, where the thermocouple junction is located inside the dosimeter holder next to the dosimeters. A black tape is used to hold the wires firm in position. The wires leave the irradiation chamber through the central access tube to the recording device situated outside the Gammacell.

Now, calculate the response (R) defined as the OD induced due to radiation:

$$R = OD(\text{mean}) - OD(\text{bkgd})$$

where, OD(bkgd) is the mean value of the OD of the unirradiated film (Form-SIT-2) which is valid for the entire lot of dosimeters (see Section 2.3.7). Calculate the corrected response value for the temperature effect, R(corr) as:

$$R(\text{corr}) = R (1.0 - 0.0073 \Delta T)$$

where,  $\Delta T = T(\text{eff}) - T(\text{cal})$ ; (note,  $\Delta T$  may be positive or negative).

For each dose level, calculate R(mean), the mean value of the three corrected response values. Again record these values in Form-SIT-4B.

#### 4.1.3. Transit dose

Transit dose is defined as the dose a sample or dosimeter receives while either the source is moving or the sample/dosimeter is moving. Transit time is then defined as:

$$\text{Transit time} = \text{Transit dose} / \text{dose rate},$$

where, dose rate refers to its value at the stationary irradiation position.

Transit time is not the physical transit (or movement) time of the dosimeters, that is the actual time the dosimeters take to go up and down. As a good approximation, the transit time is one quarter of the actual time the dosimeters take to go up and down. If the transit dose is significant compared to the minimum dose of interest (namely, 50 Gy for SIT), it is essential that this value be added to the nominal dose values (50, 80, ... 240 Gy, see Section 4.1.1) before the calibration relation is determined. We will assume here that if the transit time is less than 0.5% of the minimum irradiation time (i.e., 50Gy/dose rate), then the transit time(dose) may be ignored. For Gammacell-220 (Nordion), transit time is approximately 4 s, thus transit time(dose) may be ignored for those irradiators which have dose rate less than about 4 Gy/min. For other cases, general procedure is given below for the estimation of transit dose (this procedure applies specifically to a Gammacell-type irradiator). Annex II describes the procedure for each CRP participant.

1. Following the procedure of Section 4.1.1, irradiate one set of dosimeters each for four irradiation time periods: T1, T2, T3 and T4 seconds (use Form-SIT-4C). Annex II gives the values for T1, T2, T3 and T4 for each CRP participant.
2. Read the dosimeter sets following the procedure of Section 4.1.2.
3. Plot 'irradiation time' on x-axis vs 'R(mean)' on y-axis for these four points. Determine the relationship using regression analysis.
4. Following the same procedure, irradiate two more sets of dosimeters. Irradiate the first set for T1 seconds (as before) plus  $N_1$  times with zero-time setting (0 seconds) on the timer. Thus, the amount of extra dose this dosimeter set receives compared to the set with irradiation time of T1 seconds is  $N_1 \times (\text{transit dose})$ , which can be attributed to the extra irradiation time of  $N_1 \times (\text{transit time})$ . The second set is irradiated in a similar way, however the extra dose it is given is  $N_2 \times (\text{transit dose})$ . Annex II gives the values for  $N_1$  and  $N_2$  for each CRP participant.
5. Measure the response, R(mean) for these two sets of dosimeters following the procedure of Section 4.1.2 (use Form-SIT-4C).

6. For these two R(mean) values, determine the corresponding 'irradiation time' using the regression relationship developed in step 3 above. The values correspond to  $T1 + N_1x(\text{transit time})$  and  $T1 + N_2x(\text{transit time})$ .
7. Calculate the value of the transit time by subtracting T1 from each of these two values and dividing the first value by  $N_1$  and the second value by  $N_2$ . These two values should be similar (within a few %). The average of these two values is taken as 'transit time' for this irradiator. Enter this value in Form-SIT-4C. Note: The value of the transit time does not change with the radioactive decay of the source. However it should be measured at least once in two years, and sooner if the timer or the movement mechanism is modified.
8. Calculate 'transit dose' = 'transit time' x dose rate (of today). Enter this value in Form-SIT-4C.
9. Add this value of 'transit dose' to each of the 6 nominal dose values (namely, 50, 80, .. 240 Gy), and enter these 'Actual dose' values in Form-SIT-4D (Appendix B).

#### 4.1.4. Calibration relationship

First, copy values of 'R(corr)' and 'R(mean)' from Form-SIT-4B to Form-SIT-4D.

The objective here is to determine the relationship between the dosimeter response and the dose. This can be done graphically or with regression analysis.

For graphical analysis, plot 'R(mean)' on y axis vs 'Actual dose' on x axis as given in Form-SIT-4D (Appendix B). Draw a smooth curve through all the six points. Note: This curve may be slightly non-linear.

If regression analysis is employed, use the three 'R(corr)' values (as y-parameter) for each 'Actual dose' value (x-parameter). The relationship is almost linear, but quadratic fit may be better. The calibration relationships may be described as:

$$\begin{aligned} \text{Linear function:} & \quad \text{Response} = a + b (\text{Dose}) \\ \text{Quadratic function:} & \quad \text{Response} = c + d (\text{Dose}) + e (\text{Dose})^2 \end{aligned}$$

The selection between the two can be made by observing the distribution of the percentage residuals for the two cases following the procedure given below (use Form-SIT-4E):

1. Calculate  $D_{\text{calc}}$  for each of the three response values (R(corr)) for all six irradiations (as given in column 3 of Form-SIT-4D):

$$\begin{aligned} \text{Linear function:} & \quad D_{\text{calc}} = (\text{Response} - a) / b \\ \text{Quadratic function:} & \quad D_{\text{calc}} = (1/2e) [-d \pm \{d^2 - 4e(c - \text{Response})\}^{1/2}] \end{aligned}$$

Enter these values in Form-SIT-4E, column 2 or 4.

2. Determine the percentage residual for each point as:  
 $\text{Residual}(\%) = 100 \times (D_{\text{calc}} - D_{\text{actual}}) / D_{\text{actual}}$ ,  
 where,  $D_{\text{actual}}$  is the actual value of the delivered dose (as given in column 1 of Form-SIT-4E). Note: Residual(%) value may be positive or negative.
3. Record these values of 'Residual(%)' in Form-SIT-4E (column 3 or 5).

4. Plot 'Residual(%)' (on y axis) vs 'Actual dose' (on x axis) for the linear as well as for the quadratic fit.
5. Select the relationship that yields random distribution of the residual values as a function of dose. If both show similarly random distribution, select the linear function as the calibration relationship.

This calibration relationship is valid for the specific lot of dosimeters for one year, and for the temperature employed for the irradiations, T(cal). Enter the date of calibration, the calibration irradiation temperature, T(cal) and the calibration relationship in Form-SIT-9 (Appendix B).

Calculate the root-mean-square residual ( $u_{\text{fit}}$ ) value for the selected calibration relationship, as follows:

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

where, n is the total number of residual values (18 in this case), and the summation to be carried over all these n (=18) values. Record this value in Form-SIT-9.

Note: This value represents the uncertainty arising from the fitting procedure and will be used later in Section 4.3.

#### 4.1.5. Frequency

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

#### 4.1.6. Use of the calibration relationship

To measure dose at a point, follow the procedure given below. Use Form-SIT-5 for this procedure (Appendix B).

Irradiation:

1. Place one 1cm x 1cm dosimeter (or several) from the calibrated lot at each point of interest. Use an 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).
3. Estimate the temperature (T(eff)) of the dosimeter during irradiation (Section 4.1.1).

OD measurements (Note: These measurements are made 24 to 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 stabilise.
5. Check the high and low absorption scales and adjust the 'HI' and 'LO' knobs if necessary; repeat this procedure every thirty minutes during the OD-measurement session (see Section 2.2.1).
6. Measure the OD of the three ND filters at least once a day preferably before starting the measurements with the dosimeter films, and record the values on Form-SIT-5 and Form-SIT-1. Compare these OD values with those measured during the calibration of the dosimetry system. Different values indicate problem with the reader.

7. Remove the dosimeter(s) from the envelope and measure its OD following the procedure of Section 2.2.2.
8. Determine the response,  $R = OD(\text{measured}) - OD(\text{bkgd})$ .  
Note: If more than one dosimeter are used at one point, calculate the average value of R.
9. If the temperature during routine measurements is not the same as T(cal) (that is, the value during the calibration procedure), a correction needs to be applied as follows (also see Section 4.1.2):  $R(\text{corr}) = R (1.0 - 0.0073 \times \Delta T)$ ,  
where,  $\Delta T = \text{temperature of irradiation} - T(\text{cal})$ .
10. Determine the dose using the value of 'R(corr)' and the calibration relationship determined in Section 4.1.4.

#### 4.2. Lot homogeneity

It is important to determine the degree of homogeneity of response for dosimeters belonging to a lot since it affects the overall precision of the measured dose value. For each lot of dosimeters, this is determined by irradiating several dosimeters selected randomly from the lot to the same dose, following the procedure given below:

1. Cut nine dosimeters from the dosimeter film sheet (current lot).
2. Place these dosimeters in three small envelopes for irradiation (three dosimeters per envelope).
3. Place these three envelopes *together* at a location inside a container full of pupae (or similar material) where the dose is expected to be uniform (for example, at the centre of the container).
4. Irradiate them at about 100 Gy dose. Note: The exact values of dose and irradiation temperature are not important. However, it is very important that they all receive the *same* dose at the *same* temperature.
5. Determine the response of each dosimeter following points 4 to 8, Section 4.1.6. Record these values in Form-SIT-6 (Appendix B).
6. Calculate the mean and standard deviation of these nine response values. Determine coefficient of variation:  $CV(\%) = (\text{standard deviation}/\text{mean value}) \times 100$ .  
Record these values in the Form-SIT-6. Record the value of CV(%) as  $u_{\text{lot}}$  in Form-SIT-9.  
Note: The lower the CV(%) value the higher (better) the precision of the measured dose value.

#### 4.3. Uncertainty

In general, the result of any measurement is only an approximation or estimate of the value of the measurand (for example, absorbed dose), and thus is complete only when accompanied by a statement of the uncertainty of that estimate. Uncertainty (of measurement) may be defined as a parameter, associated with the measurand, that characterises the distribution of the values that could reasonably be attributed to the measurand. Thus, uncertainty reflects the degree of accuracy in the measured value.

Uncertainty in any measurement is a fact of life and unavoidable. First, the sources of uncertainty should be identified, and their effects minimised as much as possible. And then the remaining sources of uncertainty should be evaluated. This is most easily done by considering in turn each step in the calibration and use of a dosimeter, and assessing what uncertainties are likely to be associated with each step. The uncertainty associated with a dose measurement can then be calculated by combining the individual components together. The philosophy used is to ascribe to each component of uncertainty an effective standard deviation, known as a standard uncertainty, and these standard uncertainties are then combined to produce the total uncertainty.

The total uncertainty in the measured dose value consists of several components (Note: all these components are in %):

- $u_{dr}$  : arising from uncertainty in the dose rate value (from IDAS certificate, see Section 3.4),
- $u_{fit}$  : arising from uncertainty in the calibration relationship (see Section 4.1.4),
- $u_{lot}$  : arising from lot non-homogeneity (= CV(%) value from Form-SIT-6, see Section 4.2). If  $n$  dosimeters are used at one location to measure dose, the uncertainty in the mean value is reduced by  $\sqrt{n}$ . Thus, this component of uncertainty for  $n$  dosimeters = CV(%) $\sqrt{n}$ .
- $u_{temp-i}$ : arising from uncertainty in the irradiation temperature during dose measurement

Note: As discussed in Section 4.1.2, the measured dosimeter response 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 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 (Guide to the expression of uncertainty in measurement, 1995, International Organization for Standardization).

- $u_{temp-r}$ : arising from uncertainty in the dosimeter temperature during OD read-out procedure

Note: Assuming that the dosimeter temperature during read-out is within  $\pm 5^{\circ}\text{C}$  of the temperature during calibration,  $u_{temp-r} = 0.7 \times 5 / \sqrt{3}$  where,  $0.7\%/^{\circ}\text{C}$  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 (Guide to the expression of uncertainty in measurement, 1995, International Organization for Standardization).

The total uncertainty,  $u_{total}$  (%) 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 ( $\sigma$ ). However, to imply a higher level of confidence that the 'true' value lies within the reported range,  $u_{total}$  should be multiplied by a factor of 2 (called a 'coverage factor'). Thus, one can state with about 95% confidence that the 'true' dose value lies within  $D_{measured} \pm 2u_{total}$ .

#### 4.4. Characteristics of the current lot of dosimeters

Enter the values determined above for the following characteristics in Form-SIT-9 (Appendix B):

- ID of the lot of dosimeters,
- calibration of the dosimetry system,
- background response,
- uncertainty values.
- 

### 5. Dose distribution measurement (Dose mapping)

#### 5.1. Objective

The primary purpose of performing dose mapping is to verify that the dose variability in the irradiated sample is acceptable for the application on hand. This should be done before useful irradiation is carried out. If the distribution is wider than acceptable, it points out the need for modifying the irradiation procedure or the container size/shape.

This activity is generally referred to as 'Process Qualification' since it establishes values of all process parameters necessary to achieve the specified dose in the sample. See Section 6.3 and Form-SIT-8B for examples of process parameters.

Use Form-SIT-7 for recording data (Appendix B).

5.2. Research application

If pupae are irradiated for research purpose, such as to establish the relationship between dose and its effectiveness, it is inherently essential that the dose is as uniform as possible across the irradiated sample. To measure the dose distribution in the sample, place several dosimeters (or a strip of film) in the sample container. Note: the dosimeters should be protected in paper envelopes against contact with pupae.

5.3. Commercial application

For commercial applications, generally larger volumes are irradiated, and thus dose is not as uniform as for small volumes used for research applications. Dose variation is unavoidable, and the main objective of dose mapping is to determine the maximum and minimum dose in the container and the regions where these occur. Carry out detailed dose determination by carefully placing several dosimeters through out the irradiated volume. Place dosimeters in a specific regular grid pattern, however place more dosimeters in regions where extreme doses are expected from previous experience or from theoretical analysis. If some portion of the pupae is receiving dose too high or too low for the application at hand, some changes need to be carried out before large-scale irradiation is done.

5.4. Reference location

For process control during routine irradiation, it is necessary to place dosimeters in or on the product (pupae) container (see Section 6.2). They are preferably placed at a point where the dose is expected to be minimum. However, it is not always convenient to do so. Alternatively, a dosimeter(s) may be placed at a reference location on the product container that is convenient. During the dose mapping exercise, select such a reference location and establish the relationship between the dose at this point and the minimum dose in the product. Note: To reduce uncertainty in the process, the dose gradient at this reference location should not be significant.

**6. Process control**

6.1. General

Carry out routine irradiation as per information gathered during the dose mapping exercise; that is, ensure that the values of all the process parameters are the same as established during process qualification (Section 5.). Thus, it is expected that the dose distribution would be acceptable. On the other hand, it is necessary to have in place some measures of process control to show with a high degree of confidence that the entire process was carried out as specified. This is accomplished through two independent procedures: a) routine dosimetry, and b) monitoring of process parameters. Besides, use of radiation-sensitive indicators assist in streamlining the inventory process.

6.2. Routine dosimetry

For each irradiation batch, place at least three dosimeters (in one envelope) at the location where the dose is expected to be minimum or at the reference location identified during process qualification (Section 5.4). Thus, if the dose value (mean of the three values) measured by these dosimeters is acceptable (as established during process qualification), then it can be concluded that the particular irradiation batch has received the expected dose. Use Form-SIT-8A for recording data (Appendix B).

Note: Each laboratory should determine for itself, *what is an irradiation batch*.

6.3. Process parameter monitoring

Control, monitor and document all process parameters that can affect dose throughout the process (irradiation). Such parameters include: container size, any specific arrangement of the product/pupae within the container, positioning of the container, irradiation time/conveyor speed, rotation of the container (if applicable), and source location.

Use Form-SIT-8B for recording data (Appendix B).

6.4. Radiation-sensitive indicators

Appropriate radiation-sensitive indicators should be placed on each container before irradiation. Check the state of the indicator before and immediately after irradiation. Use of these indicators assists in keeping irradiated and unirradiated containers apart. However, there also should be administrative procedures in place to identify the irradiated samples/containers.

Note: *These indicators are not replacement for routine dosimeters. Routine dosimeters are absolutely essential as discussed in Section 6.2.*

7. **Documentation**

Document all information collected during various procedures described above and file it together at an easily accessible location. This is necessary for research applications as well as for commercial applications. Prepare and use appropriate forms to make this consistent, such as those given in Appendix B. Operators should sign and date these forms and file them as an integral part of process control for audit purposes.

**Appendix A - Modifications to the ‘Operations Manual’ of the Radiachromic® reader**

A.1 Section 2, Paragraph 2, replace the first 2 sentences by the following:

*Gafchromic® film has a polystyrene base of 97 µm(microns), 6.5 µm of active layer and 0.75 µm of gelatine. Thus, the total thickness is about 104 µm (≈ 0.1 mm).*

A.2 Figure 1 is not representative of Gafchromic® dosimetry system.

A.3 Section 3.2, Replace the text under the NOTE by the following:

*There are no extreme measures to be taken to protect the dosimeter film against UV light. However, do not expose the films to the sunlight, and keep exposure to room lights (especially fluorescent lights) to the minimum required in order to handle the films and for the measurements. Store the large film sheet(s) in their envelope after each use.*

A.4 Section 4, Point 4. For Gafchromic® dosimeter, the OD is not divided by its thickness because the thickness is constant for all the dosimeters.

A.5 Section 5.1, Points 1-8. Replace this text by Section 4.1 of this S.O.P.

A.6 Section 5.2. Not relevant.

A.7 Sections 5.3.2 and 5.3.3. Not relevant.

**Appendix B - Recommended data forms for documentation**

- B.1 Form-SIT-1 Neutral density filter OD measurements
- B.2 Form-SIT-2 Background OD for the lot of dosimeters
- B.3 Form-SIT-3 Dose rate measurement with IDAS alanine dosimeters
- B.4 Form-SIT-4A Gafchromic® dosimetry system calibration: Irradiation
- Form-SIT-4B Gafchromic® dosimetry system calibration: Response determination
- Form-SIT-4C Gafchromic® dosimetry system calibration: Transit dose determination
- Form-SIT-4D Gafchromic® dosimetry system calibration: Relationship
- Form-SIT-4E Gafchromic® dosimetry system calibration: Residual behaviour
- B.5 Form-SIT-5 Dose determination
- B.6 Form-SIT-6 Homogeneity for the lot of dosimeters
- B.7 Form-SIT-7 Dose mapping
- B.8 Form-SIT-8A Process control: Routine dosimetry
- Form-SIT-8B Process control: Process parameter monitoring
- B.9 Form-SIT-9 Characteristics of the current lot of dosimeters



**Background OD for the Lot of Dosimeters**

Note: Check and adjust the absorption scale before these measurements.

Lot ID :  
Date :  
Dose : 0 (zero) Gy  
Measured by :

<b>Dosimeter</b>	<b>OD (600 nm)</b>
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Mean OD <sup>1</sup>	
Standard Dev	

<sup>1</sup> OD(bkgd) = Mean OD for the present lot of dosimeters

Note: This value is valid for 6 months only. If the lot lasts longer, these measurements should be repeated.

**Dose Rate Measurement with IDAS Alanine Dosimeters**

Note: Also attach here copies of the two IDAS data sheets

Date :

Irradiated by :

<b>IDAS Dosimeter set number</b>	
<b>Reference field</b>	
Irradiator	
Dosimeter holder ID	
Holder location	
<b>Irradiation temperature (°C)</b>	
Controlled?	Yes <input type="checkbox"/> No <input type="checkbox"/>
Measured value	Before = °C ; After = °C ; Other .....
<b>Irradiation time</b> <sup>1,2</sup>	
<b>Dose rate</b> <sup>3</sup>	

1 when and how was the timer calibrated:

2 Is this measurement based on an automatic timer? Yes  No

If it is done manually, when was the timer started and stopped ?

3 Dose rate = Dose (from IDAS certificate, Section 3.5) / Irradiation time  
 Note: It is assumed that transit dose is negligible compared to the dose value

When was the dose rate measured last time:

Were the irradiation conditions the same?

What was the value then?

Any other remarks:

Gafchromic® Dosimetry System Calibration: Irradiation

Date :

Reference field and dosimeter holder:

(should be the same as those used for the dose rate measurement with alanine (Form-SIT-3))

Dose rate (of today) (from Section 4.1.1) :

Irradiated by :

Nominal Dose (Gy)	Irradiation Time <sup>1,2,3</sup>	Min. Temp. (°C)	Max. Temp. (°C)	T(eff) <sup>4</sup> (°C)
50				
80				
120				
160				
200				
240				

1 For example, Irradiation time = 50 Gy/dose rate (of today)

2 when and how was the timer calibrated:

3 Is this measurement based on an automatic timer? Yes  No

If it is done manually, when was the timer started and stopped ?

4  $T(\text{eff}) = T(\text{minimum}) + 2/3 \{T(\text{maximum}) - T(\text{minimum})\}$

$T(\text{cal}) = \text{average of the six } T(\text{eff}) \text{ values} =$

**Gafchromic® Dosimetry System Calibration: Response Determination**

Note: - Check and adjust the absorption scale every 30 minutes.  
 - Measure the OD values for the three ND filters just before and just after the following measurements and enter the values here and in Form-SIT-1.

Date :

Analysed by :

OD of the three ND filters (before the measurements): , , .  
 OD of the three ND filters (after the measurements) : , , .

Nominal Dose (Gy)	OD			OD (mean)	OD (std dev)	Response <sup>1</sup> (R)	R(corr) <sup>2</sup>	R(mean) <sup>3</sup>
	3 values for each strip							
50	A:							
	B:							
	C:							
80	A:							
	B:							
	C:							
120	A:							
	B:							
	C:							
160	A:							
	B:							
	C:							
200	A:							
	B:							
	C:							
240	A:							
	B:							
	C:							

- 1 Response, R = OD (mean) – OD (bkgd), where OD (bkgd) is from Form-SIT-2
- 2 R(corr) = R(1.0 – 0.0073 x ΔT), where ΔT = T(eff) – T(cal), where T(eff) and T(cal) are from Form-SIT-4A.
- 3 R(mean) = Average of the three R(corr) values in column 6

NOTE:

Calculate the coefficient of variation (CV) for each dosimeter set (A, B and C) as:

$$CV (\%) = \{OD(\text{std dev})/OD(\text{mean})\} \times 100$$

This value should be less than 2%.

**Gafchromic® Dosimetry System Calibration: Transit Dose Determination**

Note: - Check and adjust the absorption scale every 30 minutes.  
 - Measure the OD values for the three ND filters just before and just after the following measurements and enter the values here and in Form-SIT-1.

Date :

Analysed by :

OD of the three ND filters (before the measurements): , , .  
 OD of the three ND filters (after the measurements) : , , .

Irrad. Time	OD			Response <sup>1</sup> (R)	R(corr) <sup>2</sup>	R(mean) <sup>3</sup>
	3 values for each strip					
T1	A:					
	B:					
	C:					
T2	A:					
	B:					
	C:					
T3	A:					
	B:					
	C:					
T4	A:					
	B:					
	C:					
T1 + N <sub>1</sub> ·TT	A:					
	B:					
	C:					
T1 + N <sub>2</sub> ·TT	A:					
	B:					
	C:					

- 1 Response, R = OD (mean) – OD (bkgd), where OD (bkgd) is from Form-SIT-2
- 2 R(corr) = R(1.0 – 0.0073 x ΔT), where ΔT = T(eff) – T(cal), where T(eff) and T(cal) are determined for this set of irradiations
- 3 R(mean) = Average of the three R(corr) values in column 6

NOTE: T1, T2, T3 and T4 are the times set on the automatic timer. If the irradiation chamber is operated manually, the time period is the one during which the chamber is stationary in the irradiation position.

Transit time =  
 Transit dose (on date ..... ) = Transit time x dose rate (of today) =

Gafchromic® Dosimetry System Calibration: Relationship

Date :

Calibration temperature, T(cal) :

Analysed by :

Nominal dose (Gy)	Actual dose (Gy) <sup>1</sup>	R(corr)	R(mean)
50		A:	
		B:	
		C:	
80		A:	
		B:	
		C:	
120		A:	
		B:	
		C:	
160		A:	
		B:	
		C:	
200		A:	
		B:	
		C:	
240		A:	
		B:	
		C:	

1 Actual dose = Nominal dose + transit dose

Graphical Analysis:

Plot 'Actual dose' on x-axis and 'R(mean)' on y-axis

Regression Analysis:

Y-variable = R(corr) (column 3), thus there are three y-values for each x-value.

X-variable = Actual dose.

Fit the data to linear as well as quadratic relationship.

Attach all the graphs to this Form.

**Gafchromic® Dosimetry System Calibration: Residual behaviour**

For regression analysis

Date :

Analysed by :

Actual dose <sup>1</sup> (Gy)	Linear Relationship		Quadratic Relationship	
	D <sub>calc</sub> <sup>2</sup>	Residual(%) <sup>4</sup>	D <sub>calc</sub> <sup>3</sup>	Residual(%) <sup>4</sup>
	A:	A:	A:	A:
	B:	B:	B:	B:
	C:	C:	C:	C:
	A:	A:	A:	A:
	B:	B:	B:	B:
	C:	C:	C:	C:
	A:	A:	A:	A:
	B:	B:	B:	B:
	C:	C:	C:	C:
	A:	A:	A:	A:
	B:	B:	B:	B:
	C:	C:	C:	C:
	A:	A:	A:	A:
	B:	B:	B:	B:
	C:	C:	C:	C:

1. Values from column 2, Form-SIT-4D.
2. D<sub>calc</sub> = Calculated dose for the corresponding value of 'R(corr)' from Form-SIT-4D, and using the linear calibration relationship.
3. D<sub>calc</sub> = Calculated dose for the corresponding value of 'R(corr)' from Form-SIT-4D, and using the quadratic calibration relationship.
4. Residual(%) = 100 x (D<sub>calc</sub> - D<sub>actual</sub>) / D<sub>actual</sub> ,  
Note: Residual(%) value may be positive or negative.

Plot 'Residual(%)' as y-parameter and 'Actual dose' as x-parameter for each relationship.

Select the relationship that yields random distribution of the residual values as a function of dose. If both show similar random distribution, select the linear function as the calibration relationship.

Attach all the graphs to this Form.



Homogeneity for the Lot of Dosimeters

Note: Check and adjust the absorption scale before these measurements.

Lot ID :  
 Date :  
 Dose : approximately 100 Gy  
 Analysed by :

Dosimeter	Response (600 nm)
1	
2	
3	
4	
5	
6	
7	
8	
9	
Mean Response	
Standard Deviation	
Coefficient of Variation (%) <sup>1</sup>	

<sup>1</sup> CV(%) = {standard deviation/mean value} x 100

NOTE: This value should be less than 2%. If it is more, report to the Scientific Secretary of the CRP



Process Control: Routine Dosimetry

Date :

Irradiation batch/run ID :

Analysed by :

OD of the three ND filters (before the measurements): , , .

OD of the three ND filters (after the measurements) : , , .

Dosimeter <sup>1</sup>	Temp(°C) <sup>2</sup>	OD <sup>3</sup>	Respo. <sup>4</sup>	R(corr) <sup>5</sup>	Dose(Gy) <sup>6</sup>	Remarks <sup>7</sup>
						<i>Reference location</i>
						<i>Minimum dose</i>

NOTE: This is the same form as Form-SIT-5 and -7. However, the dosimeters are placed either at the location of minimum dose or at the reference location identified during dose mapping (see Section 5.4 and Form-SIT-7)

1. Identification of the dosimeter. This information should also appear on the small envelope in which the dosimeter was irradiated and where it is stored.
2. Estimated temperature of the dosimeter *during* irradiation.
3. Measured OD of the dosimeter.
4. Response = measured OD – OD(bkgd)
5. Corrected Response (for temperature) = Response(column 4) [1.0 – 0.0073 x ΔT]  
Where, ΔT = Temperature (column 2) – T(cal)
6. Dose calculated using R(corr) from column 5 and the calibration relationship (from Section 4.1.4).
7. Enter information re: irradiation batch, product, location of dosimeter, etc.

**Process Control: Process Parameter Monitoring**

Date :

Irradiation batch/run ID :

Operator :

*Please add any other process parameters that are relevant to your process*

<b>Parameter</b>	<b>Description / Value</b>
Species	
Bulk density of the insects	
Source location	
Container size	
Product arrangement in the container	
Container location	
Container rotated ?	No <input type="checkbox"/> Yes <input type="checkbox"/> Speed =
Irradiation duration / Conveyor speed	

Characteristics of the Current Lot of Dosimeters

Lot ID: 7726-09 (*Gafchromic*® dosimeter sheets received from the IAEA)

<b>Calibration of Gafchromic® dosimetry System</b> (Section 4.1.4)		
Date of calibration (valid for one year)		
Calibration temperature, T(cal)		
Relationship		
<b>Background Response</b> (Section 2.3.7)		
Date of measurement (valid for 6 months)		
OD(bkgd)		
<b>Uncertainty values</b> (Section 4.3)		
Arising from dose rate (Section 3.4)	$u_{dr}$ (%) =	date =
Arising from calibration (Section 4.1.4)	$u_{fit}$ (%) =	date =
Arising from lot non-homogeneity(4.2)	$u_{lot}$ (%) =	date =

## Annex I

### IDAS irradiation dose for each CRP participant

Note: 1) Time of irradiation (Tofl) should be such that the transit time  $< 0.005 \times \text{Tofl}$ . For example, if the transit time is 4 seconds, time of irradiation for IDAS should be about 14 minutes or more.  
 2) IDAS dose  $> 600 \text{ Gy}$

	Laboratory	Irradiator	Dose rate (Gy/min)	IDAS		Holder	Remarks
				Dose, Gy	Irrd time		
1	Argentina (Taret)	IMCO-20	40 Gy/pass	600	15 passes	Panoramic	Speed to be adjusted 1 pass = in and out
2	Australia (Fogliani)	Gammacell (Nordion)	18	600	35 min	Cylinder	Irradiator not in use
3	Chile (Donoso)	Gammacell (Nordion)	250 (assumed)	3,500	14 min	Cylinder	Dose rate is needed
4	Guatemala (Caceres)	Gammacell (JLSheppard)	77	1,100	14 min	Cylinder	
5	Guatemala (Caceres)	Husman	31	Not necessary		-----	
6	Japan (Kuba)	Pool type	10	2,000	200 min	Panoramic	Irradiate in fixed position
7	Lebanon (Abi- Chahine)	Issledovatel	90	6,300	70 min	Cylinder	
8	Mexico (Liedo)	Gammacell	81	1,100	14 min	Cylinder	
9	Peru (Quenta)	G.beam127	2.7	650	4 hour	Cylinder	No change in the table position
10	Philippines (Resilva)	Gammacell (JLSheppard)	1.9	600	5.25 h	Cylinder	
11	Portugal (Pereira)	Gammacell (Nordion)	143	2,000	14 min	Cylinder	
12	U.S.A.- Hawaii	Husman	30	600	20 min	Cylinder	'Transit time' ~ 3 sec

**Annex II**

**Information for determination of transit time for each CRP participant**

	Laboratory (participant)	Dose rate (Gy/min)	T1 <sup>e</sup> (sec)	T2 (sec)	T3 (sec)	T4 (sec)	N1	N2	TD <sup>f</sup> (Gy)
1	Argentina (Taret) <sup>a</sup>	~40Gy/pass	-----	-----	-----	-----	-----	-----	-----
2	Australia (Fogliani)	18	180 <i>54</i>	240 <i>72</i>	300 <i>90</i>	360 <i>108</i>	7 <i>62</i>	15 <i>72</i>	1.2
3	Chile (Donoso)	250 (assumed)	30 <i>125</i>	60 <i>250</i>	90 <i>375</i>	120 <i>500</i>	3 <i>176</i>	7 <i>244</i>	17
4	Guatemala (Caceres)	77	60 <i>77</i>	120 <i>154</i>	180 <i>231</i>	240 <i>308</i>	7 <i>112</i>	15 <i>152</i>	5
5	Guatemala (Caceres) <sup>d</sup>	31	-----	-----	-----	-----	-----	-----	2
6	Japan (Kuba)	10	300 <i>50</i>	600 <i>100</i>	900 <i>150</i>	1200 <i>200</i>	5 <i>75</i>	10 <i>100</i>	5(?)
7	Lebanon (Abi-Chahine)	90	60 <i>90</i>	120 <i>180</i>	180 <i>270</i>	240 <i>360</i>	3 <i>186</i>	6 <i>282</i>	32
8	Mexico (Liedo)	81	60 <i>81</i>	120 <i>162</i>	180 <i>243</i>	240 <i>324</i>	7 <i>116</i>	15 <i>156</i>	5
9	Peru (Quenta)	2.7	1200 <i>54</i>	1380 <i>62</i>	1560 <i>70</i>	1740 <i>78</i>	7	15	<1
10	Philippines (Resilva) <sup>b</sup>	1.9	-----	-----	-----	-----	-----	-----	0.1
11	Portugal (Pereira)	143	30 <i>72</i>	90 <i>215</i>	150 <i>358</i>	210 <i>501</i>	7 <i>142</i>	15 <i>222</i>	10
12	U.S.A.- Hawaii	37	90 <i>56</i>	150 <i>93</i>	210 <i>130</i>	270 <i>167</i>	7 <i>74</i>	15 <i>94</i>	2.5

a – transit time has no meaning for this type of irradiator (IMCO-20)

b – dose rate is less than 4 Gy/min, hence the transit time/dose is insignificant and not needed

d – this participant has a Gammacell also, hence does not need this information for Husman irradiator

e – numbers in italics are the corresponding approximate values of dose in Gy

f – approximate value of transit dose in Gy, based on transit time of 4, 4 and 21 seconds for Gammacell, Husman and Issledovatel, respectively.