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Exposure meters and dosimeters — General methods for testing

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FOREWORD

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 4071 was developed by technical committee ISO/TC 85, *Nuclear energy*, and was circulated to the member bodies in March 1977.

It has been approved by the member bodies of the following countries :

Australia	France	Spain
Austria	Japan	Sweden
Belgium	Mexico	Switzerland
Brazil	Netherlands	Turkey
Canada	New Zealand	U.S.A.
Czechoslovakia	Poland	U.S.S.R.
Finland	Romania	Yugoslavia

The member bodies of the following countries expressed disapproval of the document on technical grounds :

South Africa, Rep. of
United Kingdom

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Exposure meters and dosimeters – General methods for testing

0 INTRODUCTION

This International Standard constitutes a guide to defining and carrying out general methods for testing exposure meters and dosimeters[1] used in radiation protection for X-rays and gamma rays with energies below or equal to 3 MeV. It will subsequently be complemented by a second document dealing with rate meters and, in the more distant future, by a third document relating to dosimeters used in the presence of neutrons or gamma rays with energies above 3 MeV. However, study of this latter point necessitates the parallel establishment of definitions of suitable reference radiations.

This International Standard describes a large number of tests from which, in drawing up specifications for a given type of dosimeter or exposure meter, the tests applicable to that type can be selected. The details of the test methods selected, the choice of parameters and the conditions of measurement will be laid down in the particular standards or specifications applying to the dosimeters considered.

To simplify the carrying out of the tests, the methods have been drafted in such a way that each can be read on its own, independently of others.

This International Stnadard merely defines the general test methods and does not deal with the way in which the test results should be interpreted in order to evaluate the qualities of the dosimeter. Such interpretation may be studied in the particular standards applying to the dosimeters considered.

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies general methods of testing dosimeters used in radiation protection for X-rays or gamma radiation of energies below or equal to 3 MeV. It therefore allows a check to be made of whether dosimeters comply with the requirements stated in particular standards or specifications, and allows comparison of various types of dosimeters.

The tests are designed to be carried out on the dosimeter equipped with the operating accessories specified by the manufacturer.

2 REFERENCES

ISO 1757, *Personal photographic dosimeters.*[2]

ISO 4037, *X and γ reference radiations for calibrating dosimeters and dose ratemeters and for determining their response as a function of photon energy.*

ISO 3768, *Metallic coatings – Neutral salt spray test (NSS test).*

IEC Publication 359, *Expression of the functional performance of electronic measuring equipment.*

1) Throughout this text, the generic term "dosimeter" is used to mean both exposure meters and dosimeters.

2) At present at the stage of draft. (Revision of ISO/R 1757-1971.)

3 CLASSIFICATION OF DOSIMETERS

The method adopted for classifying dosimeters, shown in table 1, is based on the effect which reading them has on the information stored, and is intended to enable general test methods to be described.

4 GENERAL REFERENCE CONDITIONS FOR DOSIMETERS TESTS

4.1 Ambient conditions

Except in special cases, most of the tests can be carried out in the following atmospheric conditions[1] :

- temperature between 15 and 35 °C;[2]
- relative humidity between 45 and 75 %;[2]
- atmospheric pressure between 70 and 106 kPa.[2]

The actual atmospheric conditions should be indicated in the test report. They should not undergo large or rapid changes during a series of measurements.

For acceptance tests, it is recommended that the following standard conditions be used :

- temperature : 20 ± 2 °C;
- relative humidity : (65 ± 5) %;
- atmospheric pressure : 90 ± 10 kPa.

When the dosimeters being tested are sensitive to the effects of magnetic or electromagnetic fields, the continuous background of these fields, in the place where the tests are carried out, should not exceed $1/m$ of the threshold sensitivity of the instruments.[3]

4.2 Irradiation conditions

Use, from a qualitative point of view, the reference radiations defined in ISO 4037.

For tests calling for an absolute measurement, these reference radiations must be known quantitatively and in relation to the class of apparatus.

The exposure or exposure rate used for the carrying out of the test must be frequently checked with a reference instrument which has itself been compared with the national standard apparatus.

For tests calling for a comparison of measured values, these must be reproducible within ± 2 %.

Except in the case of special tests, the irradiation should be made perpendicularly to the principal axis or to the sensitive surface of the dosimeter.

The distance "source-dosimeter" is defined as the distance from the centre of the equivalent point source to the geometric centre of the sensitive part of the detecting element of the dosimeter.

The exposure rate due to the natural radiation background, that coming from the container and any possible contamination must not exceed a certain threshold[4] depending on the sensitivity of the apparatus. Whenever, for practical reasons, this threshold is exceeded, that fact must be taken into account.

TABLE 1 — **Classification of dosimeters**

Class	Effect of reading	Examples of actual dosimeters included in the class
Class A	Reading destroys neither the information nor the dosimeter; resetting to zero is possible	Direct reading dosimeters with electroscope Some capacitor dosimeters with indirect reading Some dosimeters with an electrometer
Class B	Reading destroys neither the information nor the dosimeter; resetting to zero is impossible (except after complicated laboratory processes)	Photoluminescent, semi-conductor and coloured glass dosimeters Exceptionally, some dosimeters with an electrometer Most chemical dosimeters
Class C	Reading destroys the information but not the dosimeter	Most thermoluminescent dosimeters
Class D	Reading does not destroy the information, but renders the dosimeter unusable for further measurements	Photographic emulsion dosimeters Exceptionally, some chemical dosimeters

1) These conditions do not apply to climatic tests (series II).

2) These figures have been selected as best suited to dosimeter tests. They may be adjusted according to particular climatic conditions.

3) The value of m will be fixed according to the particular specifications for each type of apparatus.

4) This threshold will be determined by the particular specifications for each type of dosimeter.

If a radioactive source is used, the duration of irradiation must be much longer (at least 100 times longer) than the times for approaching and withdrawing the source. If this condition cannot be met, the exposure resulting from the times during which the source is being approached and withdrawn must be precisely determined in each case; depending on the test carried out the order of magnitude of the duration of irradiation must be chosen so as to avoid introducing additional errors due, for example, to the effects of :

- the exposure rate;
- leakage.

To facilitate irradiation in the best possible conditions, reproducible within ± 2 %, the dosimetry room should meet the following specifications :

- the irradiation table and supports for the dosimeters should be made of a material of low atomic number (so far as is compatible with the necessary rigidity);
- the dosimeter should be placed so that only the gamma radiation reaches it and so that the scattered radiation has an energy spectrum as constant as possible and does not exceed 5 % of the exposure received directly;
- the distance between dosimeters should be such that no dosimeter affects its neighbours;
- the position of the source (in the irradiation position) and that of the dosimeter should be reproducible within ± 1 mm from one test to another;
- in order to subject several dosimeters of the same batch to the same exposure, their supports should be placed on the dose rate contours (circles). If sufficient homogeneity cannot be achieved, the irradiation table may be made to rotate around the source.

4.3 Reading conditions

In testing dosimeters based on a given principle, whenever possible the same standard reading device of known accuracy should be used.

Before each series of readings, switch on the reference reading device and wait long enough for it to be stabilized.

Before each series of readings, check the zero error of the reference reading device and, if the instrument allows, its correct functioning at some other point.

In addition to photographic dosimeters, any dosimeter which is sensitive shall only be taken out of its case at the time of reading or processing and under conditions prescribed in documents specific to the dosimeters considered.

If the dosimeters have batteries or accumulators, these should be protected during the functioning tests in series II (tests 2.1, 2.2, 2.3 and 2.4) described below. They should be removed for the storage tests of series II (tests 2.5 and 2.6) and series III (test 3.5) described below.

Except for certain special tests, readings should be made after allowing time for the dosimeter response to stabilize.

If a recording system can be connected to the reading device, it is desirable that this adaptation does not affect the reading and that direct readings be supplemented by a recording.

5 TESTS

The tests have been classified in four series :

- **Series I :** Tests with X or gamma radiations for energies below or equal to 3 MeV.
- **Series II :** Climatic tests.
- **Series III :** Mechanical tests.
- **Series IV :** Utilization tests.

5.1 Series I — Tests with X or gamma radiations for energies below or equal to 3 MeV

5.1.1 *Test 1.1 — Zero point stability*

5.1.1.1 Principle

To determine the initial indication of the dosimeter before any irradiation takes place and how this indication changes with time.

5.1.1.2 Procedure

Class A :

Before any other test, set *n*[1] dosimeters to zero.

Store them under the specified climatic conditions and then read them without resetting them to zero.

The times of storage and or of holding before reading will be laid down by the particular specifications.

Class B :

Store *n*[1] dosimeters under the specified climatic conditions, then read them.

The times of storage and of holding before reading will be laid down by the particular specifications.

1) In this test, as in the following ones, the value of *n* will be laid down in the particular specifications for each type of dosimeter.

Class C :

Set to zero as many times n[1] dosimeters as there are waiting times before reading laid down in the particular specifications. At the end of each of these times, withdraw n dosimeters and read them.

Class D :

Upon receiving them, process and read n[1] dosimeters. After the time laid down in the particular specifications, process and read a further n dosimeters in the same conditions; repeat this test after each of the times laid down in the particular specifications.

5.1.1.3 Results

All classes :

a) For each time, calculate :

– the mean $\overline{l_0}$ of the initial indications of the dosimeters;

– their standard deviation s.

b) Plot the curve showing the change with time of the initial indication of the dosimeter.

5.1.2 *Test 1.2 – Stability of information*

5.1.2.1 Principle

To determine how the information given by the dosimeter varies according to the time which elapses between irradiation and reading, all other conditions remaining unchanged. In particular, the climatic conditions must remain within the reference conditions and the temperature should not vary by more than ± 5 °C from the initial temperature of the test, while remaining within the reference limits.

5.1.2.2 Procedure

The test should be carried out with the shortest possible irradiation time. The time shall be such that the dosimeter reading will not be affected by the dose rate or the accuracy of the chronometer used.

Class A :

Irradiate n dosimeters with an exposure between 50 and 85 % of the calibration or of the scale range normally used and read them as soon as possible after the irradiation (within 15 min) and after each of the times laid down in the particular specifications.

Class B :

As for class A.

Class C :

Irradiate as many times n dosimeters as there are holding times before reading laid down in the particular specifications, with an exposure between 50 and 85 % of the calibration or of the scale range normally used. Withdraw and read n dosimeters as soon as possible after irradiation (within 15 min) and after each of the times laid down.

Class D :

Proceed as appropriate in one of the two following ways :

– Irradiate with the same exposure and in the same conditions as many times n dosimeters as there are holding times before reading laid down in the particular specifications, process them after each of these times and read them.

– Irradiate at staggered intervals (so that the holding times before processing will be those laid down by the particular specifications) with the same exposure and under the conditions laid down by the particular specifications, as many times n dosimeters as there are specified holding times before reading, plus n control dosimeters. Process all these dosimeters simultaneously as soon as possible after the irradiation of the control dosimeters, and read them.

5.1.2.3 Results

All classes :

a) For each time, calculate :

– the mean $\overline{l}$ of the readings;

– their standard deviation s;

– the ratio r of this mean to the exposure read immediately after irradiation.

b) Plot the curve of r as a function of time.

5.1.3 *Test 1.3 – Repeatability*[2]

5.1.3.1 Principle

To determine the repeatability of the measurements made with the same dosimeter subjected to the same exposure in identical conditions.

5.1.3.2 Procedure

Class A :

Set n dosimeters to zero.

1) In this test, as in the following ones, the value of n will be laid down in the particular specifications for each type of dosimeter.

2) **repeatability** : The closeness of agreement between successive results obtained with the same method on identical test material, under the same conditions (same operator, same apparatus, same laboratory and short intervals of time). [ISO 3534.] Repeatability depends upon the dosimeter and the reading device.

Irradiate them with an exposure between 50 and 85 % of the calibration or of the scale range normally used, then read and reset them to zero.

Repeat the test ten times in succession.

If the reading device has several ranges, proceed as described above for each of them.

Class B :

The test cannot be applied to dosimeters of this category, since they cannot be reset to zero.

Class C :

Set n dosimeters to zero.

Irradiate them with an exposure between 50 and 85 % of the calibration or of the scale range normally used, then read them.

Repeat the test ten times.

If the reading device has several ranges, proceed as described above for each of them.

Class D :

This test cannot be applied to dosimeters of this class, since reading renders them unusable.

5.1.3.3 RESULTS

Classes A and C :

For each operation, calculate :

- the mean $\overline{l}$ of the ten readings;
- their standard deviation s.

5.1.4 *Test 1.4 – Batch homogeneity*

5.1.4.1 PRINCIPLE

To investigate the dispersion of the response of the dosimeters submitted to the same exposure under the same conditions (including same laboratory and same operator) and in particular to determine whether this dispersion can be expressed as a normal law (after having taken account of the possible corrections due to the repeatability).

5.1.4.2 PROCEDURE

All classes :

a) *Sampling*

Assuming the distribution to be normal, withdraw at random n_0 dosimeters ($5 < n_0 \leqslant 10$) from the batch to be examined, irradiate them with the same exposure and read them.

Calculate the mean $\overline{l_i}$ of the readings l_i of the dosimeters and the standard deviation s_0 of these readings (s_0 being a first estimate of the standard deviation for the whole batch).

$$\overline{l_i} = \frac{1}{n_0} \sum_1^{n_0} l_i$$

$$s_0 = \sqrt{\frac{\sum_1^{n_0} (l_i - \overline{l_i})^2}{n_0 - 1}}$$

Choose :

- the percentage error b that can be tolerated on the reading of the exposure l, to determine the margin of error :

$$d \approx \frac{b}{100} \overline{l_i}$$

- the risk α that the estimate is made with an error equal to or greater than d.

Deduce an approximate value n of the number of specimens necessary in order to make an estimate with risk α by means of the formula :

$$n = \left(t_{\alpha, n_0} \frac{s_0}{d} \right)^2$$

t_{α, n_0}, the variable in Student's law, being given by table 2.

TABLE 2 – **Values of t_{α, n_0}**

n_0 \ α	0,1	0,05	0,02	0,01
6	2,015	2,571	3,365	4,032
7	1,943	2,447	3,143	3,707
8	1,895	2,365	2,998	3,499
9	1,860	2,306	2,896	3,355
10	1,833	2,262	2,821	3,250

b) *Selection and test*

Select at random n specimens from the whole batch, and irradiate them with an exposure between 50 and 85 % of the calibration or of the scale range normally used.

Read the dosimeters at equal times after irradiation, since the indication given by the dosimeter varies with time.

5.1.4.3 RESULTS

Plot the frequency diagram for the exposures read (the number of class intervals not being less than 5 in any case).

Calculate the mean value $\overline{l}'$, of the readings of the dosimeters of the sample, and the corresponding standard deviation s'. (Or trace the Henry line and deduce from it another estimate of the mean $\overline{l}''$ and of the standard deviation s''.)

Verify that the hypothesis (of a normal distribution) is correct by a χ^2 test with a risk α.[1]

5.1.5 *Test 1.5 — Lower limit of reading*

5.1.5.1 PRINCIPLE

To determine :

a) the detection threshold, i.e. the minimum exposure for which the reading obtained is significantly different from the standing indication. The readings corresponding to this value are such that :

$$\overline{l} - \overline{l_0} \geqslant \sqrt{2} \times 1{,}96\, s_{l_0}$$

where

$\overline{l}$ is the mean of the readings for the exposure in question;

$\overline{l_0}$ is the mean of the initial readings either of the batch of dosimeters subjected to test 1.1, "Zero point stability", or of the dosimeters being tested;

s_{l_0} is the standard deviation of the initial readings.

When the initial readings are mostly zero, it is better to simplify the formula to :

$$\overline{l} - l_{0\,max} \geqslant 1{,}96 s$$

where

$\overline{l}$ is the mean of the readings for the exposure in question;

s is the standard deviation of these readings;

$l_{0\,max}$ is the maximum value of the initial readings.

b) the lower limit of reading at x %[2] : i.e. the minimum exposure for which the mean value of the readings having a dispersion ($\overline{l} \pm 2s$) is such that :

$$\left(\frac{100 - x}{100}\right) L \leqslant \overline{l} - 2s < \overline{l} + 2s \leqslant \left(\frac{100 + x}{100}\right) L$$

where

$\overline{l}$ and s are as defined above :

L is the value read for the test exposure on the linear part of the calibration curve obtained from the graph of the variations of $\overline{l}$ as a function of the exposure during the course of the test. (See figure 1.)

5.1.5.2 PROCEDURE

Class A :

Set n dosimeters to zero.

Irradiate them with an exposure X.

Read them.

Repeat these operations for exposures corresponding to, say :

$2X$, $3X$, $4X$, $5X$, $6X$, $7X$, $8X$, $9X$, $10X$, $15X$, $20X$, $30X$, $40X$, $50X$, $100X$,

X being defined by the absolute value of the error in reading or a multiple of this value, according to the precision expected from the combination of the dosimeter and reading device.

Class B :

Take the initial reading of p batches of n dosimeters.

Irradiate one batch with each of the exposures defined for class A.

Read them.

Class C :

Proceed as for class A.

Class D :

Proceed as for class B.

5.1.5.3 RESULTS

a) For each exposure, calculate :

— the mean $\overline{l}$ of the readings;

— their standard deviation s.

b) Plot the graph of $\overline{l}$ as a function of the exposure.

c) Determine the threshold of detection by means of the inequalities defined in 5.1.5.1.

d) Determine graphically the value of the lower limit of reading at x %.

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1) The same method can be used for the statistical investigation of the variables obtained from other tests.

References for test 1.4 :

— NBS Handbook 91 : *Experimental statistics*, Library of Congress Catalog : 63 60 072.

— *Le contrôle statistique des fabrications*, R. CAVE, Eyrolles.

2) x will be laid down in the particular specifications.

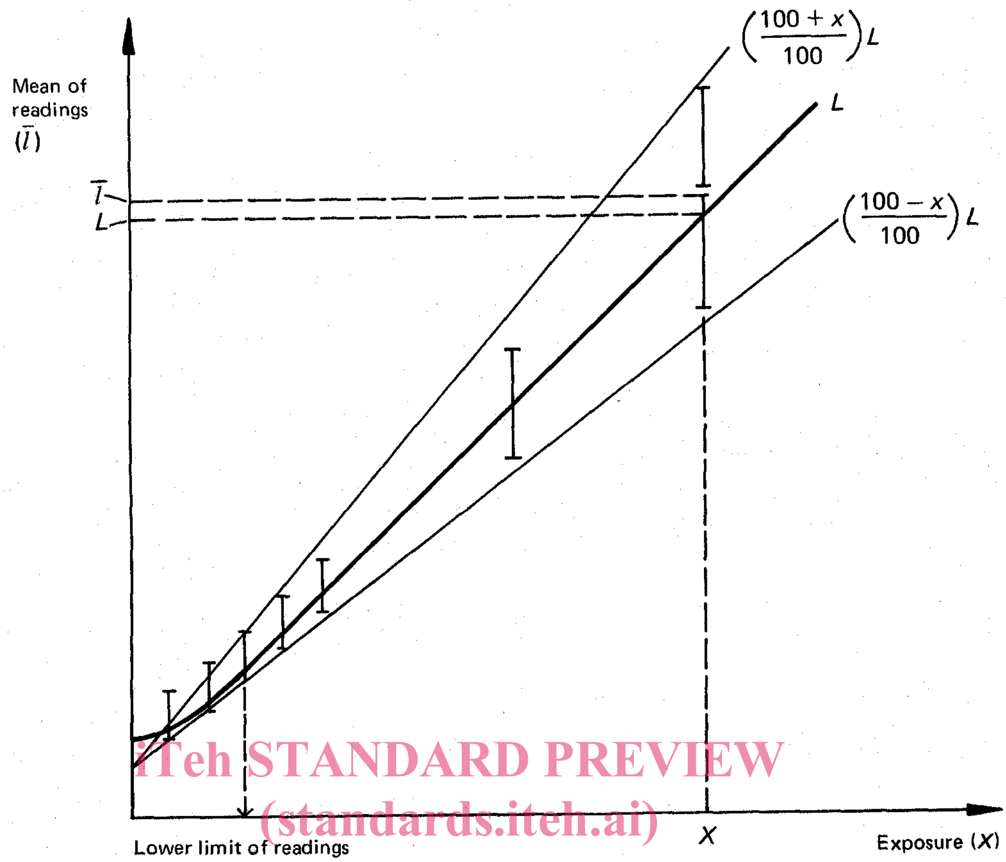

FIGURE 1

5.1.6 *Test 1.6 – Exactness*[1] *and linearity*

5.1.6.1 Principle

a) To determine the ratio : $\dfrac{\text{exposure read}}{\text{exposure received}}$

b) To study the variation over the whole range of measurements.

5.1.6.2 Procedure

Class A (Dosimeters having generally only one effective range) :

Take the n dosimeters subjected to test 1.5, "Lower limit of reading", and set them to zero.

Irradiate them successively with the exposure X_0 corresponding to the lower limit of reading, with at least two exposures equally spaced between X_0 and the exposure corresponding to 85 % of the calibration or the effective range of the scale normally used, and with the exposure corresponding to 85 % of the calibration.

Read them and reset them to zero after each irradiation.

Class B (Test of linearity and additivity) :

Take dosimeters not previously exposed and observe their initial reading (l_0).

Irradiate them successively with exposures such that the cumulative total of the exposures is equal to the values shown in table 3 for a dosimeter with three effective ranges. When the dosimeter has n effective ranges ($n > 3$), proceed for intermediate ranges as for the second effective range.

Read the dosimeters after the reading has become stabilized (see test 1.2, "Stability of information").

Class C :

Take the n dosimeters having been subjected to test 1.5, "Lower limit of reading". If these dosimeters have received high exposures, an additional operation to erase them may be necessary.

Irradiate them successively with exposures equal to the values in table 3.

Read them.

1) **exactness** : The quality which characterizes the capability of a measuring instrument to give indications equal to the conventionally true value of the measured quantity.

Class D :

Take p lots each of n dosimeters.

Irradiate them respectively with exposures equal to the values in table 3.

Process and read them.

5.1.6.3 Results

Class A :

Calculate :

- the mean $\overline{l}$ of the readings of the n dosimeters;
- the ratio of this mean to the exposure received;
- the standard deviation s of the readings and of the ratio; plot the curve as a function of the exposure received.

Class B :

For each cumulative exposure X_i, calculate :

- the mean $\overline{l_{(X_i)}}$ of the readings of the n dosimeters;
- the ratio ϱ of this mean to the cumulative exposure received X_i :

$$\varrho = \frac{\overline{l_{(X_i)}} - \overline{l_0}}{X_i}$$

- the standard deviation s of the readings and of the ratio ϱ; plot the curve giving ϱ as a function of the cumulative exposure received.

Class C :

Proceed as for class A.

Class D :

For each batch (corresponding to a given exposure) calculate :

- the mean $\overline{l}$ of the readings of the n dosimeters;
- the ratio ϱ of this mean to the exposure received;
- the standard deviation s of the readings and of the ratio ϱ; plot the curve giving ϱ as a function of the exposure received.

5.1.7 *Test 1.7 — Memory effect (Remanence)*

5.1.7.1 Principle

To determine the effect of the past history of the dosimeters on :

- the lower limit of reading;
- the response.

5.1.7.2 Procedure

a) *Memory effect produced by irradiations corresponding to normal use of dosimeters :*

Class A :

Take a number of dosimeters equal to the number used for tests 1.5, "Lower limit of reading", and 1.6, "Exactness and linearity", and irradiate them k times at one of the exposures used in test 1.6 between the lower limit of reading X_0 and 85 % of the calibration or of the effective range on the scale normally used.

The number k shall correspond to an economical use of the dosimeter by the user.

TABLE 3 — **Cumulative exposure**

	Cumulative exposure		Reading
First effective range			l_0 (initial reading)
	X_0	lower limit of reading	$l_{(X_0)}$
	X_1, X_2	points equally spaced between X_0 and X_3	$l_{(X_1)}$, $l_{(X_2)}$
	X_3	= 85 % of $C1$, where $C1$ is the value of the first effective range	$l_{(X_3)}$
	X_4	$= C1$	$l_{(X_4)}$
Second effective range	X_5, X_6	points equally spaced between X_4 and X_7	$l_{(X_5)}$, $l_{(X_6)}$
	X_7	= 85 % of $C2$, where $C2$ is the value of the second effective range	$l_{(X_7)}$
	X_8	$= C2$	$l_{(X_8)}$
Third effective range	X_9, X_{10}	points equally spaced between X_8 and X_{11}	$l_{(X_9)}$, $l_{(X_{10})}$
	X_{11}	= 85 % $C3$	$l_{(X_{11})}$