IAEA/WHO NETWORK OF SECONDARY STANDARD DOSIMETRY LABORATORIES

SSDL NEWSLETTER

Prepared by the
Joint IAEA/WHO Secretariat
of the SSDL Network

Published semi-annually by the
International Atomic Energy Agency
Vienna

CONTENTS

No. 39 July 1998

ISSN 1011-2669

EDITORIAL NOTE

This issue of the Newsletter opens with the note on “x-ray calibration qualities”. The IAEA Technical Report Series No.374 “Calibration of Dosimeters Used in Radiotherapy” (IAEA, Vienna, 1994) is intended for hospitals and SSDLs that carry out calibration of therapy level dosimeters. It specifically makes the recommendation to use the set of x-ray qualities, given in Table II and Table III of the report, for determining what radiation quality they should offer for calibration. Many readers have expressed their curiosity regarding the set of x-ray radiation qualities recommended in the report. Others simply refer to them as the “IAEA Qualities”. We have asked Dr. J.E Burns (National Physical Laboratory, U.K) who had originally derived these sets of x-ray qualities for the NPL, to write a clarifying note on this subject which is included in this issue. It is our hope that SSDLs that have accumulated some experience in the use of these qualities and those recommended in ISO 4037, will provide us with their comments .

The second article is a report from the First Research Co-ordination Meeting (RCM) for the Coordinated Research Projects (CRP E2.40.07) on “the Development of a Quality Assurance Programme for Radiation Therapy Dosimetry in Developing Countries”, held at the IAEA Headquarters from 6 to 10 October 1997. The objective of this CRP is to help developing countries establish External Audit Groups (EAGs) in charge of TLD based quality assurance networks in radiotherapy. For that, a Quality Manual has been prepared and should help the EAGs in the establishment of the TLD methodology used for the audits. The guidelines, prepared within this CRP, are based on the recommendations of ISO series 9000, ISO/IEC Guide No.25 and benefit from the experience of the IAEA and the European Quality Assurance networks.

The third article is also a report from the Second Research Co-ordination Meeting (RCM) for the Co-ordinated Research Projects (CRP E2 40 06) on “Characterization and Evaluation of High-Dose Dosimetry Techniques for Quality Assurance in Radiation Processing” which was held at the IAEA Headquarters in Vienna, from 6 through 10 October 1997. This CRP investigates the influence of various external parameters on the performance of several routine dosimeters presently in use, and a possible transfer dosimetry system for electron beams of energy less than 4 MeV.

The present staff at the Dosimetry and Medical Radiation Physics (DMRP) Section is:

Name	Position/tasks	E-mail address
Andreo, Pedro	Head, DMRP Section	p.andreo@iaea.org
Bera, Pranabes	Laboratory Technician (TLD)	p.bera@iaea.org
Czap, Ladislav	Laboratory Technician (Ionization chamber calibration)	l.czap@iaea.org
Girzikowsky, Reinhard	Laboratory Technician (high dose dosimetry)	r.girzikowsk@iaea.org
Izewska, Joanna	TLD Officer, Head, Dosimetry Laboratory Unit	j.izewska@iaea.org
Meghzifene, Ahmed	SSDL Officer, Editor SSDL Newsletter	a.meghzifene@iaea.org
Mehta, Kishor	Radiation Processing (high dose) Dosimetry Officer	k.mehta@iaea.org
Nagaoka, Kazonuri	Laboratory Physicist (TLD) (TA)	k.nagaoka@iaea.org
Pernicka, Franticek	Diagnostic Radiology Dosimetry Officer (TA)	f.pernicka@iaea.org
Toelli, Heikki	Brachytherapy Dosimetry Officer	h.toelli@iaea.org
Salzer, Annelise	Secretary	a.salzer@iaea.org
Turk, Kathleen	Secretary	k.turk@iaea.org
DMRP Section		dosimetry@iaea.org[a]

[a] This is the general e-mail address of the DMRP Section where all correspondence not related to specific tasks of the staff above should be addressed. Please note also that there is a considerable circulation of the staff of the Agency, so that messages addressed to someone who has left might be lost. All incoming messages to this mailbox are internally distributed to the appropriate staff members.

X-RAY CALIBRATION QUALITIES

J E Burns, Teddington, UK

Since the recent publication of IAEA Technical Reports Series No. 374 "Calibration of Dosimeters Used in Radiotherapy", there have been a number of queries about the origin of, and the rationale behind, the X-ray qualities recommended for calibration purposes as listed in Tables II and III of that publication.

The simple answer is that these are the qualities derived at the UK National Physical Laboratory (NPL) in 1971 for the calibration of therapy-level dosimeters and which are still in use for that purpose. As some SSDLs may have difficulties in adopting these exact combinations of kV and filtration, it may be helpful to discuss the basic ideas involved, and how to go about deriving a different series of qualities. But first, a brief historical review might be of interest.

Brief history

From the early 1900s NPL tried to respond to the requests of British radiotherapists to calibrate the dosimeters they used for standardising the dose delivered to patients. In those days electrical (or electrostatic) methods of measuring dose were rather unreliable, and the dosimeters in general use were "pastilles" - chemicals which changed colour when irradiated. Calibration was little more than standardisation, so that radiotherapists could exchange information about suitable dosages.

The main problem hampering progress was the absence of a suitable quantity and unit for the measurement of X-ray "intensity". This was solved by the decision by the International Congress of Radiology in 1928 to define the roentgen in terms of the amount of ionisation produced in a unit volume of air. Within a few months NPL had constructed a free-air chamber to realise this quantity and unit, and began to use it to calibrate radiation dosimeters.

From the beginning, the particular kVs chosen to generate the X-ray beams at NPL were intended to match those used in clinical radiotherapy, which in those days were generally in the range 100 kV to 150 kV. As the years passed by, X-ray technology improved, and the range of qualities used for radiotherapy expanded. It increased upwards in energy to 300 kV as radiotherapists demanded X-ray generators capable of giving greater depth doses. It also extended downwards in energy because a variety of skin diseases (not just malignant) were treated by radio-therapy at X-ray voltages down to 10 kV using special beryllium-window X-ray tubes.

In attempting to meet the demand for a wider range of X-ray qualities for the calibration of radiation dosimeters, NPL added qualities on a piecemeal basis, by devising each quality in response to a request from a radiotherapist and then adding that quality to the list of those generally available. In consequence, by 1970, although the range of qualities was quite wide, it bore little resemblance to logic or convenience. In particular, the exposure rates used for the different qualities differed widely, as did the spectral widths. This gave rise to difficulties when users wanted to interpolate between different qualities in order to calculate the calibration factors for the qualities

used in a particular hospital. Therefore, in 1971 it was decided to rationalise the scheme and to derive a completely new range of X-ray qualities.

Specification of X-ray quality

For many years hospital physicists had been using half-value layer (HVL) in order to specify the quality of X-ray beams. It was decided therefore to adopt this concept and to specify the energies of low energy X-ray beams in terms of HVL in aluminium up to 4 mm Al HVL (about 100 kV), and in terms of HVL in copper for the higher energy X-ray beams up to 4 mm Cu HVL (about 300 kV). A total of nineteen qualities were chosen, at standardised values of HVLs spaced as evenly as possible, so that it would be easy for users to interpolate between them. That decision was easy, but much less obvious was the combination of kV and filtration that should be used for each quality.

Choice of kV-filter combinations

As the basic criterion was that the conditions should match those used in radiotherapy as far as possible, a review of the radiological literature was carried out to try to discover what combinations of kVs and filters radiotherapists actually used. There was a slight problem. Before about 1935 X-ray technology was not able to provide the highest and lowest energies that radiotherapists really wanted. After about 1955 the main interest of radiotherapists was concentrated on using the new opportunities offered by the development of ^{60}Co and ^{137}Cs teletherapy units and megavoltage X-ray generators. During this period there was the second world war. However, it was assumed that the requirements for low- and medium-energy X-ray therapy had not changed significantly since that time.

Interestingly, the review indicated that there were two extreme views. On the one hand there were those who used high kVs and low filtrations; these had the advantage of high exposure rates enabling large numbers of patients to be treated in the shortest possible times, but had the dis-advantage of a high skin dose relative to the tumour dose, thus often preventing the required tumour dose to be delivered because of unacceptable skin reaction. The other extreme was to use highly filtered beams, the main advantage of which was to reduce the skin dose, but needed long treatment times, thus making radiotherapy rather expensive. It appeared however that most radiotherapists steered a middle course between these two extremes, and it was these conditions that were felt to be most appropriate for the new NPL calibration qualities.

The new NPL X-ray qualities

Taking this into account, together with a decision to try to keep the same kerma rates over the range of qualities, after a certain amount of trial and error the X-ray qualities listed in TRS 374 were derived, shown here as Tables 1 and 2. Over the range 0.35 mmAl HVL to 4.0 mmCu HVL, these all give air kerma rates of about 100 mGy/min at 75 cm from the target, keeping the tube current fixed at the maximum allowed by the manufacturer. For lower X-ray energies, calibrations at NPL are usually carried out at 50 cm from the target, thus increasing the kerma rate, but below

about 0.5 mmAl HVL the kerma rate decreases with energy, partly because of the effect of air attenuation.

As an added bonus it was found that these conditions gave rise to very similar relative spectral widths over the whole range of qualities, i.e. the width of the photon energy spectrum divided by the mean photon energy was approximately constant.

TABLE 1. LOW-ENERGY X-RAY QUALITIES
(Table II of TRS 374}

Tube voltage (kV)	Added filtration (mm Al)	HVL at 50 cm (mm Al)
Typical inherent filtration: 1 mm Be		
8.5	None	0.024
10	0.025	0.036
11.5	0.05	0.05
14	0.11	0.07
16	0.20	0.10
20	0.30	0.15
24	0.45	0.25
34	0.47	0.35
41	0.56	0.50
44	0.74	0.70
50	1.01	1.00

A new concept of radiotherapy qualities

A year or two later it was noticed that if the kVs were plotted against the HVLs on log-log graph paper, they fell on straight lines. It was also noticed that if the same plots were made for the qualities provided by some other primary standardising laboratories for calibrating therapy-level X-ray dosimeters, these fell on almost the same straight lines, although with rather more scatter around the lines. It was felt therefore that this was the most satisfactory method of deciding whether a set of qualities is appropriate for calibrating therapy-level dosimeters, rather than just listing a set of kV-filter combinations. This is the reason for the recommendation contained in Fig. 3 of TRS 374 (Fig. 1 in this note).

If similar graphs are plotted for X-ray qualities suitable for calibrating protection-level dosimeters, keeping constant kerma rates over the whole range of qualities, their kVs also fall on straight lines when plotted against HVL, but on different straight (or almost straight) lines. An example is given in Fig. 2.

TABLE 2. MEDIUM ENERGY X-RAY QUALITIES
(Table III of TRS 374)

Tube voltage (kV)	Added filtration (mm)			Half-value layer (mm)	
	Sn	Cu	Al	Al	Cu
Typical inherent filtration: 1 mm Be					
32	0	0	0.47	0.35	-
39	0	0	0.56	0.50	-
43	0	0	0.74	0.70	-
50	0	0	1.01	1.00	-
*Typical inherent filtration: 2.5 mm Be + 4.8 mm PMMA**					
50	0	0	0.7	1.0	0.030
75	0	0	1.5	2.0	0.062
100	0	0	3.4	4.0	0.15
105	0	0.10	1.0	5.0	0.20
135	0	0.27	1.0	8.8	0.50
*Typical inherent filtration: 4 mm Al equivalent + 4.8 mm PMMA**					
180	0	0.42	1.0	12.3	1.0
220	0	1.20	1.0	16.1	2.0
280	1.4	0.25	1.0	20.0	4.0

* PMMA: polymethylmethacrylate

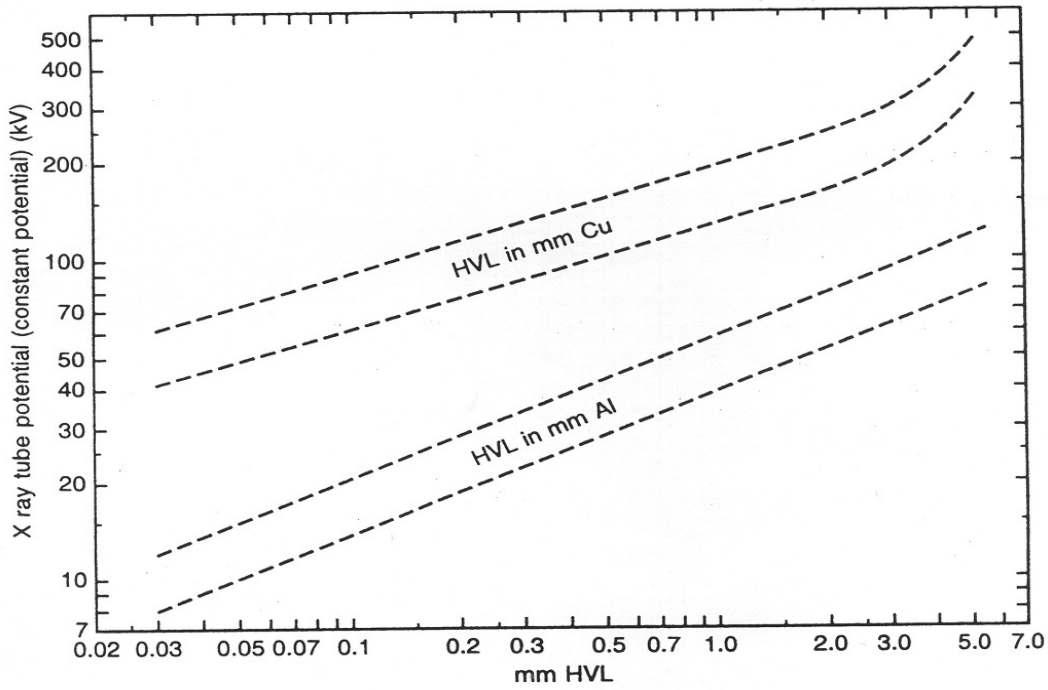


Fig. 1. Ranges of acceptable HVLs at various tube voltages (Fig. 3 of IAEA TRS 374).

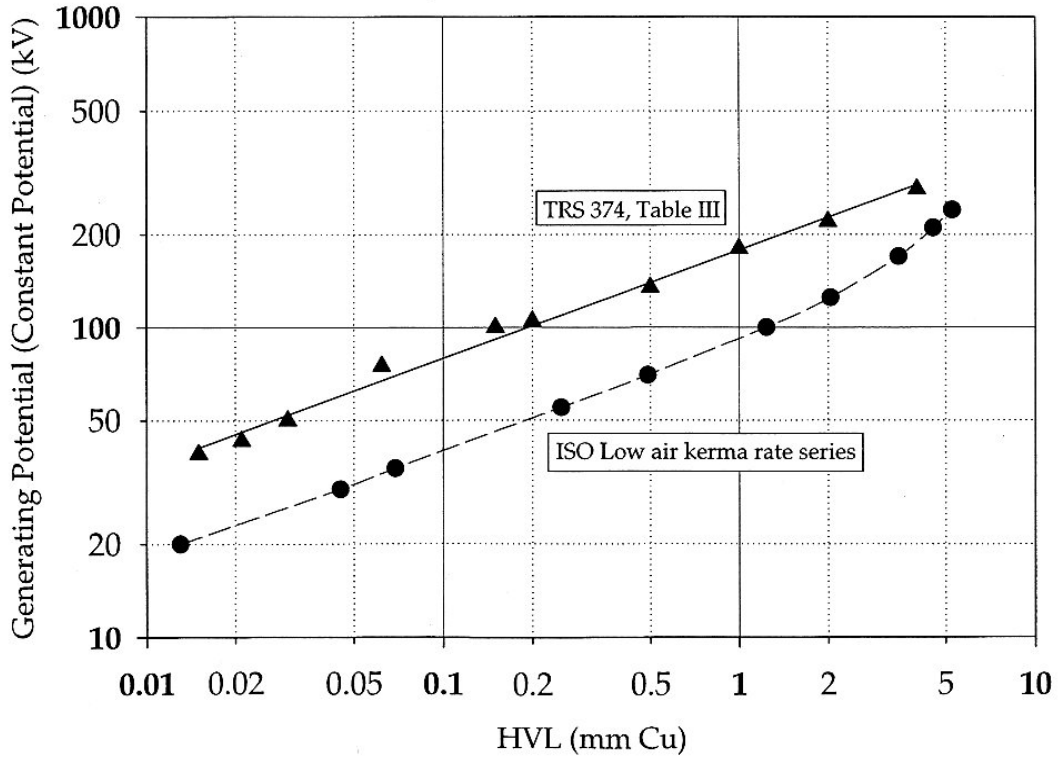


Fig. 2. Comparison of X-ray beam qualities suitable for calibrating dosimeters used in radiotherapy (taken from IAEA TRS 374) with beam qualities suitable for calibrating dosimeters used in radiation protection (taken from ISO Standard 4037).

Problems in devising new qualities

As mentioned earlier, the NPL qualities (and therefore those in TRS 374) are at standardised values of HVLs. This makes it easiest for users to interpolate between the qualities, but it does entail using some apparently strange kVs and filtrations, for example 0.5 mmAl HVL is obtained by using 41 kV and a 0.56 mmAl filter. If an SSDL found that this combination of kV and filtration did not give exactly 0.5 mmAl HVL, then it might be tempted to find a different combination. If so, a word of caution is necessary. This procedure is very time consuming, as it involves successive changes of kV and filtration, together with measurements of HVL and kerma rate, until the correct combination is found. Remember that increasing the kV increases both HVL and kerma rate, whereas increasing the filtration increases the HVL but decreases the kerma rate. Even when one has carried this out for a few qualities and become familiar with the procedure, to derive the correct combination for a single quality will still take not less than about three hours - about half a day's work.

This procedure also assumes that the SSDL possesses sheets of pure aluminium and copper and tin with a wide range of thickness down to at least 0.1 mm, and also an X-ray generator whose kV is continuously adjustable (i.e. not in steps). If the range of thickness is not available, then a quicker procedure is to take the nearest thickness available and to adjust the kV until it gives the required kerma rate, which must have been decided previously, and to check that the quality is within the range recommended in Fig. 1. If on the other hand various thickness of filters are available but that only fixed kVs are available on the X-ray generator which have been preset by the manufacturer, then choose the nearest kV and adjust the filtration until it gives the required kerma rate. Both of these procedures will give HVLs that are not standard values, but this is unavoidable. If the generator has pre-set kVs and only a few filtrations are available, then one can only try to find conditions within the suggested ranges given in Fig. 1, using the tables as a guide for kV-filter combinations.

Choice of filter material

Now a word about the choice of aluminium, copper or tin as filters. For qualities below 4.0 mmAl HVL, aluminium is the best material, because copper filters would be too thin and fragile. The aluminium should be at least 99.9% purity. For qualities above about 4.0 mm Al (0.15 mm Cu) HVL, aluminium becomes less effective in hardening the beam, and copper is a better material. ("Hardening" the beam means attenuating the lower photon energies more than the higher energies). However, copper has a K-absorption edge at 9 keV which allows it to transmit photons with a range of energies just below 9 keV, so a 1 mm thick aluminium filter must be added after (i.e. further from the target than) the copper filter in order to absorb the unwanted photons.

Similarly, for qualities above about 2.5 mm Cu HVL, copper becomes less effective at hardening the beam, so tin should be used instead. Because tin has a K-absorption edge at 29 keV, a copper filter (0.25 mm thickness would be satisfactory) should be added after the tin filter, followed by a 1 mm thick aluminium filter as before.

Inherent filtration

Finally, the tables in TRS 374 give typical inherent filtrations for the X-ray tubes. These are mainly for guidance when ordering the tubes. It is a feature of these X-ray tubes that the inherent filtration may gradually change during the lifetime of a tube because of target material being sputtered on to the X-ray window. It is necessary therefore to check about every six months that the beams are still giving the same HVLs and kerma rates that were determined when the conditions were set up. Slight adjustments to the kV or filtration may then be necessary to restore the original HVL. If large changes are found, this may mean that the surface of the target has been corroded by the electron beam, and the X-ray tube needs to be replaced.

Protection-level qualities

In principle it is easier to devise a set of qualities for calibrating protection-level dosimeters, because users do not normally want to interpolate between different HVLs. The first thing to do is to choose a convenient series of kVs, and the lowest kerma rate at which the secondary standard dosimeter will give repeatable results. Then at each kV increase the filtration until the kerma rate has been reduced to the chosen value. Start with aluminium filtration at the lowest kVs, then for increasing kVs move to copper, then tin, and then lead as the main filtration material, changing to a higher atomic number material when more than about 4 mm of the lower atomic number material would otherwise be required.

When it is necessary to use a higher atomic number material, some lower atomic number filtration should be left to absorb the photons transmitted through the K-absorption edge of the higher atomic number material, so that the order of filters along the beam starting from the target is lead, tin, copper and aluminium. As the work progresses the kVs should be plotted against HVL on log-log graph paper to confirm that they fall approximately on a straight line, except at the highest kVs when they will form a smooth curve similar to that shown in Fig. 2. Adjustments to the filtration can then be made if necessary.

However, some users may want their dosimeters to be calibrated using mean photon energy instead of HVL as the quality specifier. This can only be determined from a photon energy spectrum measured with a photon spectrometer, which may not be available. The alternative then is to use one of the sets of protection-level qualities published in ISO Standard 4037, which also contains the spectral widths and mean photon energies of the qualities. (ISO 4037: 1979. X and gamma reference radiation for calibrating dosimeters and dose-rate meters. International Organisation for Standardisation, CH-1211, Geneva 20, Switzerland)

Acknowledgements

The author wishes to express his thanks to his former colleagues at NPL, in particular to Tudor Williams who carried out the experimental work to derive the new X-ray qualities, and to Colin Moretti for help in producing Fig. 2.

REPORT OF THE FIRST RESEARCH COORDINATION MEETING (RCM) FOR THE CO-ORDINATED RESEARCH PROJECT (CRP E2 40 07) ON DEVELOPMENT OF A QUALITY ASSURANCE PROGRAMME FOR RADIATION THERAPY DOSIMETRY IN DEVELOPING COUNTRIES.

IAEA, Vienna, 6-10 October 1997
Joanna Izewska, DMRP, IAEA

BACKGROUND

In 1994, a group of consultants was asked to advice the Agency on the expansion of the IAEA/WHO TLD postal dose check service for radiotherapy hospitals by transfer of know-how to the national level. The consultants advised the Agency to initiate the Co-ordinated Research Programme (CRP) to transfer the IAEA well established TLD methodology to the countries where existing resources enabled set up of the External Audit Groups - nationally recognised groups in charge of operating external quality audits for radiotherapy dosimetry. The External Audit Groups (EAG) include the SSDL, a Measuring Centre (MC) and a Medical Physics Group (MPG), and these groups work in close co-operation during all steps of the TLD audits.

The pilot countries, which were chosen for the CRP in 1994 were: Algeria, Argentina, China and India. Due to an increasing interest in the programme, Czech Republic, Israel and Malaysia joined the CRP in 1996.

The scientific scope of the CRP covered the following implementation steps, which were planned for accomplishment:

- Development of measuring systems and measuring procedures for the EAGs with regard to Co-60 beam calibration checks for dosimetric quality control in radiotherapy hospitals.
- EAG internal trial runs under the Agency's supervision to test measuring systems and measuring procedures.
- Draft of the EAG Quality Manual (quality policy, quality system and quality practice) with regard to Co-60 beam calibration checks in hospitals using for guidance ISO 9000 Series and ISO/IEC Guide 25.
- External test runs (using the Agency's TLD service and CARE programme).
- The harmonization of the different national EAG Quality Manuals for Co-60 beam calibration checks.
- Expansion of the Quality Manual to cover accelerator beam calibration checks.
- Quality control measurements using TLDs/ionization chambers in connection with appropriate phantoms for checks in non-reference conditions.
- Intercomparison of EAGs by the Agency and external quality control programme.

Most of the listed tasks have been completed during 1995-1997 and the results and experiences reported during this RCM. The last two tasks will be completed in 1998.

PRELIMINARY DISCUSSIONS

The aim of the meeting was to discuss the degree of implementation of the national Quality Assurance (QA) programmes for radiation therapy dosimetry as reported by the participants, to co-ordinate different procedures and outline future developments. The EAGs have been set-up and their structure, responsibilities and interactions between partners have been established. The approval by the Ministry of Health (or equivalent) for conducting joint activities between medical and nuclear energy authorities towards QA in radiotherapy has been obtained, and the TLD quality audit runs with a number of hospitals performed.

The review of the implementation status, experiences and achievements of the CRP during 1995-1997 were presented by the scientific secretary. The EAG methodology and procedures as developed by the CRP were discussed with three new participants: Czech Republic, Israel and Malaysia.

STATUS REPORTS FROM THE PARTICIPANTS

A presentation on the last developments of the European project on external audits was given by Prof. A. Dutreix. Other participants presented their status reports on the degree of implementation of the CRP in their countries. All participants submitted written contributions, which are presented below.

A. Dutreix, Belgium

The feasibility of a European Network for QA in radiotherapy centres has been demonstrated during recent years through a project sponsored by the European Union (EU) Commission “Europe against Cancer”. The project named “Prevention of Deviations and Accidents through Quality Assurance Programme for Radiotherapy Centres in Europe” has been conducted in close co-operation with the Dosimetry and Medical Radiation Physics Section of the IAEA.

The project has been followed by two other projects to extend the EU Network to Central and Eastern Europe. One of these projects was sponsored by the Flemish Government, the other one by the European Union. Seven countries have participated in these two projects (Czech Republic, Poland, Hungary, Slovak Republic, Slovenia, Romania and Lithuania).

The policy of the EU is not to sponsor national actions. The know-how gained during the feasibility phase should have been transferred to national bodies. Unfortunately, due to the increasing cost of health care in Western Europe, only a few countries began to set up national networks although most of them intend to do it sooner or later.

To face the present situation and to cover the increasing need for reliable external audits, the ESTRO has recently decided to fund a European Network, following the lines recommended in the reports to European Union.

The Scientific Committee, chaired by Prof. Hans Svensson, met on October 15-17, 1997 to define tasks and responsibilities. The Physics Department from Institut Gustave Roussy (Villejuif, France), led by Prof. Jean Chavaudra has accepted the heavy task of acting as the Measuring Center.

The Network should be open to all European members of ESTRO. The audits would be free of charge during the first year but the economical situation will be reviewed after one year.

The service will include beam output checks for all treatment units which have not been checked since 5 years or more or after a major repair.

For many beams, the output of which has been checked during recent years, measurements in non reference conditions will be performed as soon as possible with one of the two types of multipurpose phantom available.

Participation will be organized on a voluntary basis after announcements have been widely distributed. The Scientific Committee has suggested that a certificate be issued to encourage radiotherapists and physicists to apply for external audits.

Strict confidentiality will be assured throughout the audit chain and the results will never be published or communicated to authoritative bodies without the written authorisation of the audited centre.

A. Meghzifene, Algeria

The EAG was established in 1996. It includes a Medical Physics Group (MPG) and a Measuring Centre (MC) established within the SSDL. A radiation oncologist is associated with this EAG, as a consultant.

The IAEA methodology using LiF powder was successfully implemented in 1997 for Cobalt-60 beams. The reproducibility obtained from the readings of 100 capsules has been improved from 2.5% (in 1996) to 1% in 1997. A reproducibility study covering other TL materials (GR 200, GR 161 and GR 161A) has also been conducted.

Correction factors for non-linearity dose response and energy dependence for high energy X-rays have been experimentally determined. Some work still needs to be done in this area. The variation of the quality index determined by TLD versus the same quality index determined by ionization measurements was studied for high energy X-ray beams.

Arrangements with the Radiotherapy Centre in Leuven, Belgium, have been made to provide the MC with reference irradiations for checking the calibration factor of the TLD system.

A national quality audit check using LiF powder has been conducted for all Cobalt-60 beams.

A radiotherapy infrastructure data base was established in 1996 within the SSDL. It has been updated and transferred to the MPG.

Finally, a second draft of the EAG Quality Audit Manual has been completed and is being reviewed by professional bodies. It will then be submitted to the health authorities for approval.

M. Saravi, Argentina

Following the recommendations given during the Consultants' Meeting of the IAEA Co-ordinated Research Programme (CRP) "Development of Quality Assurance Programmes for Radiation Therapy Dosimetry in Developing Countries", held in Vienna in November

1996, a second draft version of the local EAG Quality Manual was prepared. Procedures and instructions to organize and perform TLD audits for Cobalt 60 machines were written. The local Medical Physics Group prepared a guide to be followed during technical visits to radiation therapy centres.

The response of LiF powder (Harshaw TLD 700) irradiated in high energy X-ray beams was compared with its response when irradiated in a Cobalt 60 beam. The energy correction factor was determined for nominal accelerating potentials of 6 MV, 10 MV and 15 MV. The energy correction factor permits the extension of the TLD audits to high energy X-ray beams following a similar procedure as that used for Cobalt-60 machines. Reference irradiations and blind irradiations should be obtained from a recognized radiation therapy centre (or from an EAG in another country) for quality control of the whole procedure for high energy X-ray beams developed by our EAG.

For Cobalt 60 machines four TLD audits were performed during the period between October 1996 and September 1997. The general results for 1996 show that 83/89 machines had dose deviations within the acceptance interval $\pm$5%. Follow-up of machines with dose deviations beyond the acceptable limit showed that the causes of discrepancies are related to bad positioning of the water phantom in the beam or to various calculation errors. In two cases, the Cobalt 60 units had been calibrated “in air” and errors were made when calculations were performed to obtain the dose to water. After the MPG visit, calibration in water following the IAEA-TRS 277 Protocol was adopted.

During 1997, 14 Cobalt-60 machines were selected to be audited, not only in reference conditions, but at a 10 cm depth on the central axis as well. All selected machines had good results in previous TLD audits (dose deviation within the acceptance interval $\pm$5%) and all machines belong to centres with a medical physicist on the staff. The results of this audit show that dose deviations obtained are within the acceptance limits.

Li Kaibao, China

The data base on the infrastructure of radiotherapy in China has been updated by the EAG. Questionnaire forms were mailed to each radiotherapy hospital. According to the statistical results of the mail survey, the total number of radiotherapy centres numbered 453, with a total of 667 therapy units (linacs and Cobalt-60 units). The distribution of radiotherapy equipment among the 30 provinces in the country varies, mainly depending on economic development.

A new TL reader was purchased in 1997, and its performance has been tested to assure good reproducibility and high precision of the TLD system. Therefore, adjustments of several parameters of the reader were made.

In the framework of the IAEA’s Guidelines, a Quality Manual for the China National External Audit Group on Dosimetry in Radiotherapy was prepared.

The first TLD audit run for Cobalt-60 units was carried out. Forty-five sets of dosimeters were mailed to the hospitals and 44 sets were returned to the Measuring Group for evaluation. The results of first TLD audits indicated that 84% of the beam calibrations were within the acceptance level. For deviations between 2 standard deviations and 10%, the EAG contacted the hospitals by telephone and asked for an explanation of the reason of the deviation. For deviations exceeding 10%, the hospital was requested to review immediately

the beam calibration procedure and the TLD irradiation procedure. The assistance during on-site visits was provided.

The working plan for the next step is:

- Intercomparison with the Agency's TLD system for Cobalt-60;
- A second TLD audit run for Cobalt-60 units will be carried out;
- Expansion of the TLD service to the megavoltage X-rays;
- Organization of Sub-EAGs in a few provinces.

J. Novotny, Czech Republic

The Czech Republic joined the CRP at the beginning of 1996, but even before the QA programme has been under preparation. Four basic aspects have been considered:

- Legislation, i.e. preparation of a law and subsequent regulations
- Practical performance, i.e. postal TLD audits, on site reviews, development of the procedures and completion of the equipment
- Organization of the network, i.e. management control, inspection
- Budgeting: the IAEA grants, Ministry of Health grant, contributions from the State Office for Nuclear Safety (SONS) and from radiotherapy centres.

According to the new "atomic law", which has been in effect since 1 July 1997, it is compulsory for each user of radiation therapy equipment:

- to have the QA programme approved by SONS
- to use the equipment with a valid type test certificate only
- to submit the annual QC protocol to SONS
- to have a qualified medical physicist at the radiotherapy department
- to check independently all radiotherapy equipment once a year

It was decided by SONS to establish an External Audit Group formed from experienced medical physicists working in the field, a Measuring Centre and consulting radiotherapists, which are attached to the National Radiation Protection Institute. It was also decided that, alternatively for each year, the EAG will perform a TLD postal audit for absorbed dose determination for each radiotherapy machine, a TLD and film postal audit using multipurpose phantom, and on-site audits.

The Measuring Centre was established in 1996 and the first TLD audits were performed during February 1997. Measurements and methodology used for the TLD audits are similar to those described in the guidelines proposed under the CRP. The TLD system consists of MT-N (LiF-Mg, Ti) powder from Niewiadomski Company, Poland; Harshaw 4000 TLD reader; stands and capsules obtained from the IAEA. The mean standard deviation (SD) for a "single TLD capsule" does not exceed 0.8%. An intercomparison with the IAEA has shown a very good agreement (mean deviation within 0.2%).

From February to September 1997, 66 beams were checked: three beams showed major deviations and 4 beams had minor deviations. On-site audits for major deviations revealed errors in geometry set-ups during TLD irradiation in two cases. A wrong application of the percentage depth dose caused the major error in the third beam.

The majority of photon beams will be checked till the end of 1997. For the next year, we are planning TLD audits of electron beams; some preparatory work has been started as well as a feasibility study for a multipurpose solid phantom, which was prepared within the frame of EROPAQ/EURAQA European QA projects and which has so far been tested in a few radiotherapy centres.

A Quality Manual is under preparation, all appendices including infrastructure, questionnaire, instruction sheet, data sheet are ready and regularly used. The methodology of the TLD audits is prepared and the analysis of uncertainty of the procedure has been performed. The QA manual will be ready at the end of this year (in the Czech language) and will be submitted to the SONS for approval.

A. Kannan, India

This SSDL has prepared a draft Quality Manual for the External Audit Group (EAG). The manual covers the Quality Control (QC) procedures which will be followed by the SSDL for TL dose calculations, as it is also a Measuring Centre (MC). Important steps involved in the TL dose calculations for the capsules from the participating centres in the Quality Audit are:

- annealing of the LiF powder, capsule filling, dispatch to and receipt from the Local Centres (LC), etc.
- calibration capsule preparation
- signal measurement and dose calculation procedures for the set-up at this SSDL, and
- communication of results to the participants and follow-up actions.

The quality manual also covers the procedures to be followed by the EAG.

During 1997, this SSDL carried out TLD audits for 15 high energy X-ray beams (4-18 MV) used in the country. Results obtained indicated that 12 beams showed deviations within $\pm$3%, while for 2 beams the deviations were around 4%. For the 18 MV beam, the deviation could not be evaluated because of non-availability of complete dosimetry information from the participant. On analysis of the data furnished by individual participants, it was observed that there was no uniform dosimetry procedure followed. Detailed analysis along with the results will be made available to IAEA in the immediate future.

The SSDL India participated in a TLD audit conducted by the IAEA during 1997. In addition, the reference standard ion chamber of this SSDL was sent to the IAEA for calibration at Cobalt-60, and the results are awaited. The staff of this SSDL visited an institution which showed large dose deviation for the Cobalt-60 beam and corrected the dosimetry problems.

The following investigations are proposed to be taken up during 1998:

- Influence of LiF powder weight on response at Cobalt-60
- Determination of beam quality correction factors for 6 and 10 MV X-ray beams
- Organizing 4 batches of TLD audits of which one will be only for megavoltage X-ray beams.

M. Tatcher, Israel

The Israeli EAG was set up in February 1997. Its members include physicists from the SSDL, the national TLD personnel dosimetry laboratory and a medical physics department. An oncologist participates as a consultant and liaison with radiation oncologists at the hospitals.

At present, 13 linear accelerators and 4 cobalt units are installed in Israel in 8 radiotherapy departments. The SSDL is operated jointly by the Ministry of Health and the Atomic Energy Commission (Soreq Nuclear Research Centre). The national TLD laboratory is situated at the Soreq Centre and its facilities are used for the Measuring Centre (MC). The chief physicist of the Medical Physics Department (Soroka Medical Centre) works closely with the SSDL and the TLD laboratory in connection with their EAG activities.

Since the initiation of the project, organizational meetings have taken place, duties were assigned and a practical work plan was drawn up for the first phase. Formal approval of the EAG was solicited and obtained from the Ministry of Health.

A supply of TLD-700 powder was ordered from Harshaw and tests of its properties were made at a Cs-137 irradiation facility. The first Cobalt-60 calibration of TL dosimeters took place just before the RCM, but the results were not available at the time of writing.

Some details on the distribution of radiotherapy machines, the members of the EAG and the resources of the laboratories are given in a separate document submitted at the RCM.

Plans for the next phase include:

- obtaining formal recognition of the EAG by professional organizations of medical physicists and radiation oncologists,
- refinement of the TLD handling and Cobalt calibration procedures,
- performing one or more trial TLD audits of the Cobalt machines in the country,
- extending the audit capabilities to include high energy X-ray beams,
- completion of the first draft of the Quality Manual, and
- to consider measurements in non-reference conditions.

S. Salikin, Malaysia

Malaysia joined the IAEA CRP on Development of A Quality Assurance Programme for Radiation Therapy Dosimetry in Developing Countries in 1996. In this project the output of ^{60}Co teletherapy units from six selected radiotherapy centres in Malaysia were measured by using:

- an ionization chamber (i.e. transfer chamber NE 2581); and
- the TLD system (TLD100 powder).

The standard dosimeter has been compared with the IAEA standard through the IAEA postal dose intercomparison programmes (TLD and ionization chambers) since 1989 and the deviations obtained so far have been better than 0.4%.

Irradiations of the TLD capsules by ^{60}Co teletherapy units in the selected radiotherapy centres were carried out using the IAEA water phantom 30x30x30 cm^3 at 80 cm SSD and a field size of 10x10 cm^2 at a 5 cm depth of water in horizontal beams. Each centre was requested to irradiate three of the capsules to a nominal dose of 2.0 Gy. The fourth capsule was used as a reference. In this project the dose delivered to the TLD in each centre was checked by using the transfer chamber.

The results of this project can be summarised as follows:

- only fifty percent of the participating radiotherapy centres were capable of achieving an accuracy better than ± 5 percent, in delivering an absorbed dose as required by the ICRU;
- the deviation of the individual capsules dose relative to the SSDL mean dose is better than 2.8 percent; and
- the two procedures employed in this project namely readings the transfer chamber type NE2581 and the TLD are in a good agreement and the deviation is better than 1.4 percent.

The establishment of the External Audit Group (EAG) in Malaysia has been initiated. The EAG consists of the Medical Physics Group, the SSDL, and the Measuring Centre. The details of the EAG have yet to be worked out

REVIEW OF "Guidelines for the preparation a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy"

The EAG Quality Manual[1] "Guidelines for the preparation a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy" was drafted during the Consultants Meeting, held on 11-14 November 1996. The document was developed to help achieving uniformity among different EAGs, to facilitate exchange of experiences and follow ISO 9000 and ISO/IEC. The draft of the "Guidelines" was reviewed during this RCM. A number of appendices were prepared and reviewed, including questionnaire on radiotherapy infrastructure, TLD instruction and data sheets, a flow-chart on the TLD evaluation procedures, a form for reporting the TLD results to the participants, etc. The participants requested that the completed version be published by the Agency.

FUTURE DEVELOPMENT AND IMPLEMENTATION STEPS

The discussion of future plans began with consideration of the measurements which could be done before the end of the project in 1998, first to assure good quality of the work of the Measuring Centres and secondly to extend the services offered by the EAG to the hospitals. The working schedules for individual participants were co-ordinated and goals to be achieved related to subsequent development and implementation steps of the CRP. Israel and

[1] A copy of the revised document "Guidelines for the preparation a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy" is available at the Dosimetry and Medical Radiation Physics Section.

Malaysia were encouraged to finalize completion of the initial steps of the CRP to reach adequate compatibility with the implementation level of other participants. After successful accomplishment of preparation of the methodology for the respective national QA programmes, the new participants will start auditing radiotherapy hospitals in their countries on regular basis. They will also complete implementation of the national QA Manual for EAGs according to the “Guidelines for the preparation a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy” prepared within this CRP.

With respect to the plans for 1998 the main emphasis was given to audits of the EAGs by the Agency and to external trial runs with other EAGs. All national MCs will be audited by external bodies, first by the IAEA and then by another EAG from different country. All the MCs are included in the IAEA/WHO TLD annual runs for the SSDLs. In addition, the Agency's Dosimetry Laboratory will irradiate several sets of TLDs to be evaluated by each of the EAGs. Another planned task is related to the quality control measurements using TLDs/ionisation chambers with appropriate phantoms for beam checks in non-reference conditions.

REPORT OF THE SECOND RESEARCH CO-ORDINATION MEETING (RCM) FOR THE CO-ORDINATED RESEARCH PROJECT (CRP E2 40 06) ON CHARACTERIZATION AND EVALUATION OF HIGH-DOSE DOSIMETRY TECHNIQUES FOR QUALITY ASSURANCE IN RADIATION PROCESSING

IAEA, Vienna, 6-10 October 1997

Kishor Mehta, DMRP, IAEA

1. INTRODUCTION

In many Member States the use of large Cobalt-60 gamma ray facilities and electron beam accelerators with beam energies from about 0.1 to 10 MeV for industrial processing continues to grow. For these processes, quality assurance relies on the application of well-established dosimetry systems and procedures. This is especially the case for health-regulated processes, such as the radiation sterilization of health care products, and the irradiation of food to eliminate pathogenic organisms or to control insect pests.

For radiation sterilization, the publication of the international standard ISO 11137 - *Sterilization of health care products - Requirements for validation and routine control - Radiation sterilization* and the European Standard EN 552 - *Sterilization of medical devices - Validation and routine control of sterilization by irradiation* has resulted in the standardization of requirements to ensure global harmonization. Standardized dosimetry is also valuable in the radiation processing of many widely used commodities, such as polymers, automotive and airborne components, battery parts, computers, audio and video hardware, coatings, lubricants, adhesives, and composites.

The growing worldwide interest in the use of radiation processing to improve the environment has stimulated research in the large-scale treatment of many solid, fluid, and gaseous wastes, bringing new requirements for quality control by dosimetry and process parameter monitoring. There are also the prospects of continued expansion of the radiation processing industry through the use of new high-power high-energy electron accelerators to produce intense electron beams or highly penetrating X-rays (Bremsstrahlung). Hence, there are new challenges for achieving harmonization in quality control in production as well as pilot-scale environments.

The major goal of this CRP is to investigate the factors that influence the response of dosimeters and establish procedures to improve dosimetry for quality assurance of the different types of radiation processes. This will help to unify the radiation measurements performed by different radiation processing facilities and other high-dose dosimetry users in Member States and encourage efforts to obtain traceability to primary and secondary standards laboratories. It will also aim to strengthen and expand the present International Dose Assurance Service (IDAS) provided by the Agency.

2. PROGRESS

This section describes the progress made toward meeting the CRP objectives since the Research Co-ordination Meeting (RCM) held in Washington in May 1996. Highlights from the presentations by the different participants are given here to show how the two major objectives of the CRP are being addressed. This section also gives the specific aims proposed at the last RCM to allow comparisons between the progress achieved and the stated aims and to show areas where additional efforts should be applied.

The full comprehensive reports from each participant, as presented by them at the meeting, are available in the office of the Scientific Secretary (K. Mehta).

First Objective:

The first objective is to understand and evaluate the influence of various external parameters on the performance of routine dosimeters in use at the present. Such parameters could include irradiation temperature, humidity, radiation energy, radiation type, oxygen content, light, and dose rate. It would also be important to study the effect of more than one parameter simultaneously. This should help increase the accuracy and reliability of the routine dosimetry systems.

Some specific aims to meet this first objective are:

1a: To increase the understanding of physical and chemical properties of the dosimetric materials and formulation that can improve the performance of the dosimetry systems.

1b : To improve the performance of routine dosimeters by evaluating the influences of various parameters, including atmosphere, light, temperature, humidity, time, energy spectrum, dose rate.

To meet the first objective, the influence of changes in manufacturing or analysis parameters on the performance of the dosimetry systems, and the influence of individual and combined external irradiation parameters are being studied.

1. Influence of Manufacturing and Analysis Parameters

To facilitate the commercialization of alanine-polystyrene dosimeters for large-scale use as routine dosimeters in industrial radiation processing facilities, alanine-polystyrene dosimeters for routine use are now being manufactured using an injection molding method. Injection molding introduces orientation effects which may affect the analysis results, so studies were performed to determine an acceptable analysis technique. It was found that by taking three EPR measurements with different orientations of the dosimeter in the cavity and averaging the results, the reproducibility achievable with these injection molded dosimeters for the dose range from 0.1-100 kGy is approximately 4% (2σ). The effects of the orientation in the EPR cavity on the response of alanine-polymer dosimeters of different shapes (rods with different lengths and thin films) and dosimeters prepared by different molding procedures (press-molding, extrusion, and injection-molding) were also studied.

The effect of the EPR analysis temperature on the readings from alanine-polystyrene dosimeters in the dose range of 0.1 to 10 kGy was studied in the temperature range from 0 ^{O}C to 50 ^{O}C.

The effect of the ferrous ion concentration in the solution containing ferrous sulfate and xylenol orange used for dissolving glutamine dosimeters for spectrophotometric estimation was studied, and it was found that increased ferrous ion concentration gave better response. For accurate dosimetry, the solution should be used within a few hours after its preparation.

2. Irradiation Temperature

During the irradiation of products in commercial production facilities temperature increases greater than 20 ^{O}C have been measured. Measurements of such temperature rise in products are being performed to determine the temperature experienced by routine dosimeters at different times during the irradiation cycle. For dosimeters with known temperature coefficients, the weighted average irradiation temperature will then be used to correct the response for temperature.

The effect of the irradiation temperature on the response characteristics of alanine-polystyrene dosimeters is being studied at an absorbed dose of 5 kGy for irradiation temperatures from -196 ^{O}C to 30 ^{O}C.

The effect of the irradiation temperature on dose estimation by glutamine dosimeters analyzed by spectrophotometric readout was studied, and it was found that the response is independent of temperature in the range from approximately 25 ^{O}C to 35 ^{O}C. However, at other temperatures, there is a significant temperature effect.

3. Dose Rate

Real-time measurements are also being carried out to determine the dose rates to which product boxes are subjected during processing in production irradiation facilities. From these data, the contribution to the total dose at different dose rates will be determined and the effective dose rates will be estimated.

4. Combined Effects

Present results show only slight variations in the response of the PMMA GammaChrome YR dosimeters for different gamma dose rates in the range from 0.18 to 2.7 Gy/s for irradiation temperatures from -80 ^{O}C to 60 ^{O}C. The temperature dependence of PMMA Red 4034 (at 5 kGy) shows similar behaviour for the two dose rates investigated, 0.18 and 2.7 Gy/s, between 0 ^{O}C and 25 ^{O}C. However, outside of this temperature range the dose-rate dependence was found to be significant. The behaviour of FWT-60-00 dosimeters was also investigated in the temperature range from -80 ^{O}C to 60 ^{O}C for the same two dose rates (at 5 kGy dose).

The color build-up time (i.e. color development period) for PVG dosifilm depended on the absorbed dose and the storage temperature after irradiation. If the measurements were taken at least 24 hours after irradiation, a constant absorbance value can be reliably obtained at a given dose. The phenomenon of color development related with radical decay, a tendency demonstrated by the experimental results, has contributed to the understanding of the mechanism of color development.

The response of the PVG dosifilm was within ±5% for electron beam irradiation at relative humidities in the range from 0% to 76%. The sensitivity of the response curve (i.e. the relationship of absorbance vs. dose) can be controlled by varying the composition. This allows the new routine dosimetry system to be customized for different desired ranges of electron beam dose measurements.

5. Experimental Design Analyses of Direct and Combined Effects

The likely influence of five parameters on the EPR response of pure alanine powder and LMRI alanine pellets have been tested.

The experimental design was built with 3 blocks which can be analysed independently or together. The response is modelized by a polynomial function : Response= f(Humidity before irradiation Hb, humidity after irradiation Ha, dose rate Dr, dose D, time after irradiation t) without any physical significance. From a study of the parameters affecting the evolution of the response, the results of the first experimental design showed that Ha is the most important direct effect, followed by the combined effects of humidity before or after with the other parameters. Considering the uncertainties of the experiments of this first experimental design, only trends have been extracted.

Second Objective

The second objective is to develop reference and transfer dosimetry techniques, especially for electron beams of energy less than 4 MeV and for X-ray sources. This would facilitate extension of the present IAEA's dose assurance service (IDAS) to these radiation types.

Some specific aims to meet this second objective are:

2a To propose and to test transfer dosimetry systems for radiation processing with electron beams of energy between 300 keV and 4 MeV for absorbed doses between 10^2 and 10^6 Gy.

2b To contribute to the development of new routine dosimetry systems suitable for electron beams of energy between 300 keV and 4 MeV.

2c To investigate the suitability of using existing dosimetry systems for X-rays.

2d To establish suitable irradiation geometry to achieve consistency in dose calibration and inter-laboratory comparison.

1. Transfer Dosimetry Systems for Low Energy Electrons

Work has been carried out to demonstrate the suitability of several dosimetry systems as transfer dosimeters. These systems may be used for extending the IAEA's Dose Assurance Service (IDAS) to low energy electrons (300 keV to 4 MeV).

In order for a transfer dosimeter to produce reliable results it should
- be stable in time before and after irradiation;
- have a well defined geometry and be thin compared to the range of the electrons;
- not be influenced by environmental effects both before, during and after irradiation;
- be easily mailed;
- have no significant energy dependence;

1.1 Alanine Films

Thin alanine films in the range of 100 -300 μm were shown to be suitable for use as reference and transfer standard dosimeters. Measurements were done both by EPR spectrometry and by diffuse reflection spectrophotometry (DRS). Both methods measure the presence of the same free radicals and properties with respect to influence of environmental factors are expected to be similar. The EPR method is applicable over a larger dose range than DRS but may have orientation effects during readout. The diffuse reflection spectrophotometric evaluation is not influenced by the orientation of the alanine crystals, which is unavoidable in the case of thin alanine films.

A new thin-film (100 μm) alanine-EPR dosimeter has recently been produced as a potential reference and transfer dosimetry system for electron beams in the energy range of 300 keV to 4 MeV. It has recently been tested using thin graphite calorimeters in order to evaluate the reproducibility of its response. In addition, stability and the influences of various irradiation conditions (temperature, humidity, dose rate, light, thickness variations, etc.) have been investigated in terms of its response characteristics.

1.2. Glutamine (Spectrophotometric Read-Out)

The dosimeter is a powder (50 μm glutamine) in a thin bag (25 μm polyethylene). It has been used in intercomparisons with Cobalt-60 and 0.4 - 10 MeV electrons. It has been shown to be stable and to be not influenced by humidity. The response is independent of temperature in the range from approximately 25 ^{O}C to 35 ^{O}C. However, at other temperatures it has a significant temperature dependence.

1.3. Calorimeter

Thin and total absorption calorimeters are being tested as reference dosimeters. However, since they do not have a response that is stable with time they cannot be used as transfer dosimeters. They are made of graphite (total absorption) and polystyrene (thin calorimeters). Both are useful for calibration of other dosimeters.

2. Routine Dosimeters for Low Energy Electrons

Under the current CRP, several important developments of routine dosimeters for low energy electrons (300 keV - 4 MeV) have been made. These generally fall into three categories:

2.1. Thin Calorimeters

In the case of calorimetric systems, which are typically used as reference standard or primary dosimeters, new work has shown that both polystyrene and graphite calorimeters are suitable for routine production dosimetry in low-energy electron facilities. These calorimeters have to be carefully constructed with suitable materials (insulation, heat sensor, calorimetric body). So far, 6-mm thick polystyrene calorimeters have successfully been tested as routine dosimeters in low-energy electron beams of 1.5, 2, and 4 MeV as well as in a high-energy electron beam of 10 MeV. With this system, the development includes an optimum design of thermally insulating foam material. Similar studies have recently been made with 1-mm thick graphite calorimeters for 1 and 2 MeV electron beams.

2.2. Thin Cast Films and Coatings

There have been several important developments of new thin film systems suitable for low energy electron routine dosimetry. These include radiochromic films (e.g. PVG dosifilm, PVA films containing tetrazolium salts and GafChromic coated films), alanine films (analyzed either by EPR spectrometry or diffuse reflection spectrophotometry) and optically stimulated luminescence systems (organic or inorganic fluors).

The radiochromic films are generally quite thin with sensor layers ranging between about 7-200 μm, and have been tested for routine dosimetry for electron beam energies even down to 150 keV. Studies under the CRP have concentrated on improving the performance of thin film systems.

Thin alanine films (100 μm thick) have been demonstrated to be suitable for routine electron beam dose measurements with energies as low as 300 keV, as measured by either EPR spectrometry or diffuse reflection spectrophotometry.

Thin alanine films (300 μm thick composite) analyzed by diffuse reflection spectrophotometry are being investigated with optical determination of the $CH_3CHCO_2^-$ radical anion. Calibration curves, ranges, etc. are being obtained. The response of these films was found to be greater for electrons with energies less than 4 MeV than for higher energy electrons.

The optically stimulated luminescence films consist of microcrystalline polydispersions in a polymeric matrix (e.g. acrylics, polyolefins). The organic systems that show most promise include 3-hydroxyflavone and 1-phenyl-3-mesityl-2-pyrazoline. A simple fluorimeter has been developed for routine dosimetry using excitation by near UV or blue light and quantitative analysis of green or red emitted light. Tests have also been carried out on a promising thin film (80 μm-500 μm) containing an inorganic fluor in a polymeric matrix. This latter system has been produced in large quantities and tested in the dose range of 0.1 - 100 kGy with promising results.

The dose response parameters determined for PVG dosifilm for electron beams show that the dispersion and reproducibility are acceptable for use as a new routine dosimeter in electron beam dose measurements.

2.3. Flat Bags Containing Dosimetry Material

Flat plastic bags containing solid or liquid dosimetry material of thickness from 100 μm - 5 mm were found to be suitable for dosimetry for low energy electrons. Investigations carried out with glutamine powder (using spectrophotometric read-out) proved the suitability of this system for process control in the electron energy range of 400 keV - 10 MeV.

Double-layer polymeric bags containing ethanol-monochlorobenzene dosimeter solution proved to be useful for dose and dose distribution measurements above 1 MeV.

3. Bremsstrahlung Dosimetry

Since the last RCM, there has been little progress in advancing applications of Bremsstrahlung for radiation processing. Although there is much interest in establishing Bremsstrahlung sources using high-energy, high-power accelerators, little effort has been given to this technology (e.g. in Japan). Bremsstrahlung radiation, however, remains a potentially useful radiation type for radiation processing with large throughput. Dosimetry studies should be addressed in advance for this potential wide use of Bremsstrahlung radiation.

The following three parameters are considered as primary factors affecting dosimetry of Bremsstrahlung radiation :

1. Dose rates can reach up to 500 kGy/h resulting in higher irradiation temperatures
2. Energy spectrum of Bremsstrahlung
3. Establishment of electron equilibrium

Dose rate dependence of undyed PMMA dosimeter (Radix) and alanine-polystyrene rod dosimeter was studied for Bremsstrahlung radiation obtained from 3 MeV electrons (current: 20 mA) over the dose-rate range 5 to 350 kGy/h, where a cooling plate prevented excessive temperature rise. Both dosimeters showed negligible dose-rate dependence over the studied range.

Mass-energy absorption coefficients for dosimeter materials, PMMA and alanine, for Bremsstrahlung radiations obtained from 3, 5, and 7 MeV electrons, were estimated by weighting the contribution of the entire energy spectrum spread as calculated by the DEX-code. Estimated mass-energy absorption coefficients for these two dosimeter materials for these three different Bremsstrahlung radiations were in good agreement with those estimated for Cobalt-60 gamma-rays (1.25 MeV). For both PMMA and alanine at the above photon energies μ_{en}/ρ is 0.0293-0.0263 cm^2g^{-1} (ratio of μ_{en}/ρ for PMMA and alanine to μ_{en}/ρ for water is 0.970-0.972). This result

demonstrates the feasibility of applying these existing dosimetry systems for these Bremsstrahlung radiation even though there is a broad photon energy spectrum.

3. INTERCOMPARISON

3.1 Introduction:

One of the recommendations at the last RCM was to perform an intercomparison in Cobalt-60 gamma fields, using alanine dosimeters that are being used for IDAS, to ensure that all doses quoted by the CRP participants are in agreement. A 'double-blind' intercomparison was carried out in the summer of 1997 using the standard IDAS dosimeter sets.

3.2 Protocol**:**

The protocol that was followed was similar to the one developed by the BIPM earlier for the 1995 intercomparison for the high-dose calibration laboratories. The present protocol is reproduced below.

Issuing laboratory:

International Atomic Energy Agency
Dosimetry and Medical Radiation Physics Section, Division of Human Health
A-1400, Vienna, Austria
(Attention: Mr. Kishor Mehta)

Participating irradiating laboratories: Participants of the CRP (10)

Radiation source: Cobalt-60

Gamma dose range: 15±3 kGy (dose to water)

Issuing laboratory will provide for each irradiating laboratory 4 alanine dosimeters in polystyrene capsules, along with instructions for pre- and post-irradiation care.

Dosimeter dimension: The polystyrene capsule is 50 mm long and 12 mm diameter. The wall thickness is 4 mm; enough to provide electron equilibrium for Cobalt-60 gamma rays. The alanine dosimeter inside the capsule is 30 mm long and 3 mm in diameter.

Irradiation:

- Three (3) dosimeters will be irradiated to the same dose (preferably together in the black package); the exact dose level is to be chosen by each irradiating laboratory between 12 and 18 kGy.
- Because of the finite size of the dosimeter, it is important that (i) the gamma field is fairly uniform over its entire volume; and (ii) any perturbation in the gamma field caused by the dosimeter is estimated and corrected for.
- The irradiation temperature of the dosimeters shall be monitored and controlled within ±2°C. The temperature shall not exceed 40°C. The temperature coefficient of our alanine dosimeters is +0.0023/°C.
- The 4th dosimeter is the `control dosimeter' and shall always be kept with the others except when they are irradiated. The participating laboratory shall not irradiate this dosimeter. It will be irradiated to about 2 kGy at the IAEA Laboratory before dispatching of the dosimeters.

Issuing date: early June 1997

Return date: within 5-6 weeks of the receipt of the dosimeters (to be returned by express mail). They should be in Vienna by 15 August 1997.

The irradiating laboratory will send to Mr. O. Guven (staff member of Industrial Applications and Chemistry Section of the IAEA)

-conditions of irradiation, including
  phantom material,
  irradiation temperature of the dosimeters,
  dose rate or duration of irradiation.

-description of your dosimetry system, including calibration and traceability to national standards

- details of the derivation of the dose estimates
- value of the absorbed dose delivered to the dosimeters
- full statement of uncertainty; these to be expressed in terms of 1σ (standard deviation).

The irradiating laboratory will send to the issuing laboratory (IAEA, Kishor Mehta), besides the 3 irradiated dosimeters and the control dosimeter, the values of the following critical parameters:

- measured dosimeter temperature (within 2°C accuracy),
- date of irradiation.

The Dosimetry Laboratory (Mr. K. Mehta) will send, after reading of the dosimeters (including corrections), the estimated dose value to each participating laboratory and to Mr. Guven.

Mr. Guven will then release to Mr. Kishor Mehta the data received from the participants for analysis**.**

Mr. Kishor Mehta will write the final report to be discussed at the RCM (6-9 October 1997, Vienna).

Publication: All parties shall regard the data supplied to them as confidential and shall not publish it in any form without the permission of all other parties involved. The IAEA may, at its discretion, publish the results of the intercomparison, but only in a form that does not identify the individual participants.

3.3 Data and Results**:**

The results and information about some of the important parameters are given in Table 1. Table 2 gives relevant data of the Agency's transfer dosimetry system (alanine-ESR) used for this intercomparison exercise.

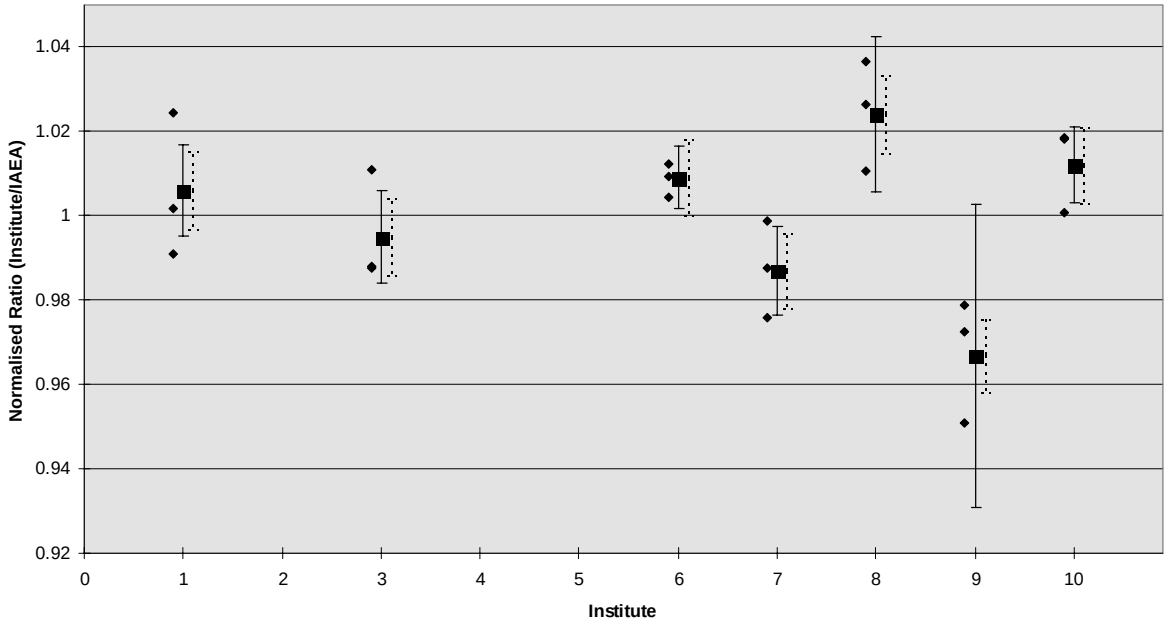
The second column of Table 1 gives the mean value of the three alanine dosimeters as analysed by the IAEA Dosimetry Laboratory, where the total uncertainty in the calculated dose is 1.7% (1σ); while the third column shows the standard deviation for the 3 individual values for a dosimeter set. The fourth column gives the dose value and the total uncertainty as stated by each participant; while the fifth column gives the non-uniformity of the gamma field over the volume occupied by the 3 dosimeters of the set (as stated by the participants). The sixth column gives the ratio (R) of the Participant's value to the IAEA value.

There are ten participants in the CRP and all participated in the intercomparison. However, during the exercise Laboratory 4 realised that they had a serious dosimetry problem in their laboratory and

were not able to state the delivered dose with high degree of confidence; they requested to opt out of this exercise. The two laboratories, namely 2 and 5, have the ratio R much outside the expected value. This indicated that they had some problem with their dosimetry system or with the procedure. (Both of these laboratories were given second set of dosimeter to repeat their irradiation. These are discussed later in the section.) Thus, these two laboratories are excluded from further analyis.

The mean and the standard deviation for the seven values of R given in Table 1 (column 6) are: mean=0.995 and std. dev.=1.9%. The ratio R was then normalised to this mean value, and this normalised R is plotted in Figure 1 for the seven participants. The bars on the left give the total uncertainty stated by the participants (column 4), and the statistical uncertainty due to the IAEA readings are shown by the bars on the right (about 0.9%). This value includes the uncertainties of temperature and fading corrections. The three dose values for each participant for the three dosimeters within a set are also shown in the figure.

Figure 1
Comparison 97 Results



3.4 Analysis:

As stated above, the mean and the standard deviation for the seven values of R as given in Table 1 are: mean=0.995 and std. dev.=1.9%. Five out of these seven laboratories are calibration laboratories; and these values for these five laboratories are: mean=0.997 and std.dev.=1.05%. Thus, the mean of the dose values measured by the IAEA is within ~1% of the mean of the dose values stated by these five laboratories. Also, the results are reasonably distributed and no outliers seem to be present (5 out of 7 are within 1σ from the mean, and the other two are within 2 σ).

The standard deviations for the three dose values for each participant have a mean value of 1.20% (column 3). A part of this uncertainty is due to the statistical uncertainty of the measurements by the IAEA (0.43%, not including fading and temperature correction contribution). The difference between these two values can be explained, at least in part, by the variation (about 1%) of the dose delivered to the dosimeters of a given set due to non-uniformity of the gamma field (column 5). The results are thus consistent with the information given by the participants.

3.5 Conclusion:

The final results of the intercomparison showed that at least two laboratories were outside the acceptance limit, and possibly a third one (Laboratory 9). This pointed out the necessity of participating in such intercomparisons frequently. This also applies to commercial irradiation facilities who avoid the extra cost of the annual intercomparisons.

3.6 Repeat Measurements:

The results from Laboratory 2 for the repeat measurements were quite different than those for the first irradiation. The only obvious difference between the two irradiations was the dose rate. For the first irradiation, the distance between the dosimeters and the plane source was about 25 cm and the dose rate was 1.068 kGy/h. For the second irradiation, these values were 15 cm and 3.072 kGy/h. The Participant/IAEA dose ratio for the second irradiation was 1.024 (compared to 0.901 before!). We do not have any explanation so far for this discrepancy.

TABLE 1

COMPARISON OF RESULTS
CRP on Characterization and Evaluation of High-Dose Dosimetry Techniques
for Quality Assurance in Radiation Processing
July-August 1997

Laboratory	IAEA estimated Mean dose (kGy) ±1.7 %	Std.Dev. for 3 values (%)	Participant's estim. Dose (kGy) ±1σ	Non - uni-formity of field	Participant / IAEA	Rel. Diff.* (%)	Doserate (kGy/h)	ΔT (days) (irr. - anal.)	Irrad. Temp. (°C)
1	14.99	1.69	15.0 ±1.09 %	--	1.001	0.07	7.69	18	26.0
2	13.10	1.03	11.8 ±3.86 %	<1%	0.901	-9.92	1.068	56	27
3	16.16	1.33	16.0 ±1.1 %	1%	0.990	-0.99	2.5	16	35
4	10.00	1.56							27;24.1;29.2
5	14.31	1.15	12.9 ±6.7 %	--	0.901	-9.85	21.8	16	31.9
6	15.26	0.40	15.32 ±0.73 %	0.3%	1.004	0.39	0.511	56	29.5
7	15.27	1.16	15.00 ±1.07 %	<1%	0.982	-1.77	10.08	14	29.0
8	12.17	1.27	12.4 ±1.8 %	<4%	1.019	1.89	4.33	11	27
9	15.59	1.51	15.0 ±3.71 %	--	0.962	-3.78	9.50	12	25.1
10	13.90	1.01	14.0 ±0.9 %	2%	1.007	0.72	9.56	16	23.3
mean:		1.20%			0.995	-0.50			
std. dev.:					1.9%	1.87			

$$* \text{ Rel. Diff. (\%)} = \frac{\text{Participant's value - IAEA estimate}}{\text{IAEA estimate}} \times 100$$

TABLE 2

Agency's Transfer Dosimetry System, alanine-ESR

Calibration Relationship (Batch No: 9512161)

$$\text{Dose (Gy)} = 6.734 + 243.5*R + 0.5745*R^2 + 5.035E\text{-}4*R^3 + 1.270E\text{-}5*R^4$$

R = Normalized Response

These regression coefficients are applicable to the Dose-range : ~1.5 … 100kGy

Calibration Conditions

- alanine dosimeters irradiated in the Agency Gammacell 220
- dose rate = 47.16 Gy/min (97-01-01)
- dose rate was determined by di-chromate transfer dosimeters from NPL
- Irradiation temperature = 25°C
- dosimeters analysed 10-20 days after irradiation

Dosimeter Characteristics

- Pre-irradiation conditioning, 7 weeks at 29% rel. humidity
- Temperature Coefficient = +0.23%/°C
- Fading rate = 0.008%/day
- Fading correction to be applied over ΔT days
  where, ΔT = (day of analysis - day of irradiation - 20) days

COURSES AND MEETINGS

Training Courses in the field of Dosimetry and Medical Radiation Physics

- Regional Course on **Dosimetry and Treatment Planning of Radiotherapy Treatments** (C7-RLA-6.035/1998). Mexico City, MEXICO, 9-21 November 1998.
- Regional Course on the **Implementation of the ARCAL XXX, Programme for Quality Assurance in Radiotherapy (Physical Aspects).** La Habana, CUBA, 23 November-4 December 1998.
- Interregional Training Course on **Quality Assurance and Procedures in SSDLs**. 1999, place and exact date not yet known.
- Regional Training Course on **Modern Techniques and Dosimetry in Brachytherapy,** 1999, African region, exact date not yet known.

Other meetings

8th SSDL Scientific Committee Meeting on evaluation of and recommendation on the dosimetry programme.	Vienna	5-9 October 1998
Consultant Meeting on the organization of regional education programmes in medical radiation physics.	Vienna	12-16 October 1998
Consultant's Meeting to develop brachytherapy calibration procedures for SSDLs.	Vienna	19-22 October 1998
International Symposium on techniques for high-dose dosimetry in industry, agriculture and medicine.	Vienna	2-5 November 1998
Consultant's Meeting on the resolution of discrepancies of SSDLs.	Vienna	16-19 November 1998

MEMBER LABORATORIES OF THE IAEA/WHO NETWORK OF SSDLS

Country	City	Contact person	Fax	E-mail
ALGERIA	Algiers	Mr. M. Arib	+213 264 8842	crsdec@ist.cerist.dz
ARGENTINA	Buenos Aires	Mr. H. Hugliaroli	+54 14800615	saravi@cnea.edu.ar
AUSTRALIA	Menai	Mr. Claudio Tuniz	+612 971732577	tuniz@ansto.gov.au
AUSTRIA	Vienna	Mr. H. Stadtmann	+43 22547802502	hannes.stadtmann@arcs.ac.at
BANGLADESH	Dhaka	Mr. A. Sattar Mollah	+880 02863051	asmollah@dhaka.agni.com
BELGIUM	Gent	Mr. H. Thierens	+32 92646699	
BOLIVIA	La Paz	Mr. Ismael Villca	+592 2433063	
BRAZIL	Rio de Janeiro	Ms. M. de Araujo	+552 14421605	mmaraujo@ird.gov.br
BULGARIA	Sofia	Mr. Z. Buchakliev	+359 2443114	ivan_dim@techno-link.com
CANADA	Ottawa	Mr. R. P. Bradley	+1 6139529646	Robert_Bradley@hc-sc.gc.ca
CHILE	Santiago	Mr. Oyarzun Cortes	+56 227318723	c_oyarzun@reina.lreina.cchen.cl
CHINA*	Beijing	Mr. Gan Zeuguei	+86 1444304	
CHINA	TaiYuan, Shanxi	Mr. Chen Mingjun		
CHINA	SIMT, Shanghai	Mr. Zhang Limin	+86 2164701810	chph@163.net
CHINA	LIH, Beijing	Mr. Li Kaibao	+86 10 62012501	shouzi@public.east.cn.net
CHINA	Kowloon-Hong-Kong	Mr. C. L. Chan	+852 29586654	cchan@ha.org.hk
CHINA	RM-IAE, Beijing	Mr. Guo Wen	+86 19357008	
COLOMBIA	Santafe de Bogota	Mr. H. Olaya Davila	+54 12220173	
CUBA	Cuidad Habana	Mr. J. Morales	+53 7331188	lscd@cphr.edu.cu
CYPRUS	Nicosia	Mr. S. Christofides	+357 2369170	g.h.library@cytanet.cy
CZECH REP.*	Prague	Mr. Kodl	+42 2738330	
CZECH REP.	CMI-Prague	Mr. P. Dryák	+420 2 67008	iizpraha@cmi.cz
CZECH REP.	RLD-Prague	Mr.D. Olejár	+42 267311410	hzackova@suro.cz
DENMARK	Bronshoj	Mr. K. Ennow	+45 44532773	
ECUADOR	Quito	Mr. H. Altamirano	+59 32253097	
EGYPT	Cairo	Mr. H. M. Eissa	+20 23612339	
FINLAND	Helsinki	Mr. H. Jarvinen	+358 9 75988450	hannu.jarvinen@stuk.fi
FRANCE	Le Vesinet		+33 139760896	
GERMANY	Oberschleissheim	Mr. D. F. Regulla	+49 8931873062	regulla@gsf.de
GHANA	Legon - Accra	Mr. C. Schandorf	+233 21773807	
GUATEMALA	Guatemala C. A.	Mr. J. A.Tovar	+502 2762007	
HUNGARY*	Budapest 126	Mr. I. Csete	+36 12120147	icsete@omh.hu
HUNGARY	Budapest XII	Mr. G. Kontra	+36 11562402	
HUNGARY	Paks	Mr. M. Orbán	+36 1551332	
INDIA	Bombay	Mr. S.C. Misra	+91 225560750	scmishra@magnum.barct1.ernet.in
INDONESIA	Jakarta Selatan	Mr. Susetyo Trijoko	+621 217657950	
IRAN	Karaj	Mr. M. Gavahi	+98 213130676	
IRAN	Teheran	Mr. H. Gharaati	+98 216428655	
IRAQ**	**Baghdad**			
IRAQ**	**Baghdad**			
IRELAND	Dublin 14	Mr. P.A Colgan	+353 12697437	rpii@rpii.ie
ISRAEL	Yavneh	Mr. S. Margaliot	+972 8434696	
KOREA	Seoul	Mr. Woong Beom Oyum	+82 23513726	11766@chollian.dacom.co.kr
LIBYA**	**Tripoli**			
MADAGASCAR	Antananarivo	Mr. R. Andriambololona	+261202235583	instn@dts.mg
MALAYSIA	Kajang	Mr. Taiman Bin Kadni	+60 3 8258262	taiman@ms.mint.gov.my
MEXICO	Mexico, D. F.	Mr. V. Tovar Munoz	+52 53297302	vmtovar@servidor.unam.mx

Country	City	Contact person	Fax	E-mail
NIGERIA**	**Lagos**			
NORWAY	Osteras	Mr. H. Bjerke	+47 67147407	hans.bjerke@nrpa.no
PAKISTAN	Islamabad	Mr. Salman Ahmad	+92 51429533	pinstech@paknet2.ptc.pk
PERU	Lima	Mr. T.B. Alvarado	+224 8991	
PHILIPPINES*	Diliman, Quezon	Mr. E. S. Caseria	+63 9201646	
PHILIPPINES	Sta. Cruz, Manila	Ms. A Lobriguito	+63 27116080	
POLAND	Warsaw	Ms. B.Gwiazdowska	+48 26449182	
PORTUGAL	Sacavem Codex	Mr. A.F de Carvalho	+351 19941995	
PORTUGAL*	Lisboa Codex	Mr. D'Assuncao Matos	+351 17266307	
ROMANIA	Bucharest	Mr. C. Milu	+40 13123426	
RUSSIA	St. Petersburg	Mr. V. I. Fominych	+7 812113 0114	
SAUDI ARABIA	Riyadh	Mr. A. Al-Haj	+966 14424777	Abdal@kfshrc.edu.sa
SINGAPORE*	Singapore	Mr. Eng Wee Hua	+ 65 7384468	
SINGAPORE	RPEDL-Singapore	Mr. S. Chong	+65 2262353	sckmipil@pacific.net.sg
SINGAPORE	SGH-Singapore	Mr. Chua Eu Jin	+65 2221720	euin@sgh.gov.sg
SLOVAK REP.	Bratislava	Ms. V. Laginová	+42 7323711	
SUDAN**	**Khartoum**			
SWEDEN	Stockholm	Mr. J-E. Grindborg	+46 87297108	jan.erik.grindborg@ssi.se
SYRIA	Damascus	Mr. M. Takeyeddin	+963 116112289	
TANZANIA	Arusha	Mr. W.E. Muhogora	+255 578554	nrtcz@habari.co.tz
THAILAND*	Bangkok	Mr. K. Bhadrakom	+66 25806013	
THAILAND	Bangkok	Mr.W. Wattanapong	+66 22234674	
THAILAND	Bangkok	Ms. W. Thongmitr	+66 25613013	
TURKEY	Istanbul	Mr. A. Turer	+902125482230	yassars@cnaem.nukleer.gov.tr
TUNISIA	Tunis	Mrs. L. Bouguerra	+216 571 630/653	
URUGUAY	Montevideo	Mrs. Anna Firpo Furth		
VENEZUELA	Caracas	Mr. F. Gutt	+58 25713164	fgutt@ivic.ivic.ve
YUGOSLAVIA	Belgrade	Mr. M. Kovacevic	+381 11455943	miljoko@rt270.vin.bg.ac.yu

** **Provisional Network members**
* **SSDL Organization**

Collaborating organizations associated with the IAEA/WHO Network of SSDLs

International Bureau of Weights and Measures (BIPM)
International Commission on Radiation Units and Measurements (ICRU)
International Electrotechnical Commission (IEC)
International Organization of Legal Metrology (IOLM)
International Organization of Medical Physics (IOMP)

Affiliated members of the IAEA/WHO Network of SSDLs

Bundesamt fur Eich-und Vermessungswesen, Vienna AUSTRIA
Australian Radiation Laboratory, Melbourne, AUSTRALIA
National Research Council, Ottawa, CANADA
Laboratoire de Metrologie des Rayonnements Ionisants, Saclay, FRANCE
Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY
National Office of Measures, HUNGARY
Electrotechical Laboratory, Tokyo, JAPAN
Rijks Institut voor Volksgesundheid, Bilhoven, The NETHERLANDS
National Radiation Laboratory, Christchurch, NEW ZEALAND
VNIIFTRI, Moscow, CIS
National Physics Laboratory, Teddington, UNITED KINGDOM
National Institute for Standards and Technology, Gaithersburg, USA