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Investigation of Alternative Means to Accomplish the Goals of Biennial Calibration of Ionization Chambers

Prepared by J. R. Cameron, L. A. DeWerd, S. J. Goetsch, J. C. Price

University of Wisconsin

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Prepared by
J. R. Cameron, L. A. DeWerd, S. J. Goetsch, J. C. Price

University of Wisconsin
Department of Medical Physics
Madison, WI 53706

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Abstract

The research described in this report was performed to investigate the feasibility of a mailed dosimetry system as an alternative method of achieving the goals of the present U.S. Nuclear Regulatory Commission requirement that ionization chambers used for calibration of cobalt-60 teletherapy units be calibrated every two years. Both thermoluminescent dosimeters (TLD's) and diode detector units were used in this study. A total of 20 hospitals in the states of Illinois, Iowa and Wisconsin participated in a program in which this dosimetry package was sent to each institution on three separate occasions. The physicist, physician or chief technologist was asked to deliver 1.50 Gray (150 rads) to the device, assuming the device was equivalent in radiation absorption characteristics to human tissue. A treatment field size of 10cm by 10cm was chosen and the institution was requested to use their clinical source-to-surface distance. The accuracy of the beam localization as indicated by the coincidence of the light field with the radiation field was measured as well. The criterion for accuracy of dose delivery was $\pm$ 5% and and the criterion for light field and radiation field coincidence was $\pm$ 3.0mm. Only two hospitals during the course of the study had both unacceptable diode meter and TLD readings simultaneously. Only one hospital had a disagreement of more than 3mm between the light field and the radiation field. It is recommended that such a mailed dosimetry package be considered as an alternative to the present NRC requirement for biennial calibration of ionization chambers used to calibrate cobalt-60 teletherapy sources.

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A. INTRODUCTION

The purpose of this research was to investigate the use of mailed thermoluminescent dosimeters and diode detectors as an alternate means to accomplish the goals of the present biennial calibration of ionization chambers, that is, for the assurance of accurate dose delivery from cobalt-60 teletherapy units. The accuracy of the institution's delivered dose and the reproducibility of our measurement techniques were of primary interest in this investigation. The study involved 20 midwestern hospitals and involved three sets of mailed measurements from each hospital at intervals of 60 days or more.

This report summarizes research concerned with the evaluation of alternate methods for assuring accuracy of dose delivery from cobalt-60 teletherapy units licensed by the U.S. Nuclear Regulatory Commission. In particular, the research bears on possible changes in Title 10 of the U.S. Code of Federal Regulations (January 31, 1983), part 35 (10 CFR Part 35), which lists special requirements for U.S. Nuclear Regulatory Commission teletherapy licensees. The regulations contained in 10 CFR ¶35.21 - ¶35.23 require full calibration measurements of teletherapy units, performance of periodic spot-check measurements of teletherapy units, and calibration of the instruments used for the full calibration and the spot-check measurements. The primary objective of the research was concerned with 10 CFR ¶35.23.

> "Section 35.23 Requirement to calibrate instruments used for full calibration and spot-check measurements.
>
> (a) Full calibration measurements required by ¶35.21 shall be performed using a dosimetry system that has been calibrated by the National Bureau of Standards or by a Regional Calibration Laboratory accredited by the American Association of Physicists in Medicine. The dosimetry system shall have been calibrated within the previous two years and

after any servicing that may have affected system calibration.

(b) Spot-check measurements required by ¶35.22 shall be performed using a dosimetry system that has been calibrated in accordance with paragraph (a) of this section. Alternatively, a dosimetry system used solely for spot-check measurements may be calibrated by direct intercomparison with a system that has been calibrated in accordance with paragraph (a) of this section. This alternative calibration method shall have been performed within the previous one year and after each servicing that may have affected system calibration. Dosimetry systems calibrated by this alternative method shall not be used for full calibration measurements."

In November of 1981, a Petition for Rulemaking (PRM-35-2), was submitted by the American Association of Physicists in Medicine (AAPM). The AAPM maintained that a two year interval was too short a time between calibrations because the National Bureau of Standards (NBS) and the Accredited Dosimetry Calibration Laboratories (ADCL's) could not provide the number of instrument calibrations needed. This petition requested revision of 10 CFR ¶35.23(a) and ¶35.25(a) to allow for a longer interval between calibrations. This research will provide useful information to the U.S. Nuclear Regulatory Commission to aid in determining the appropriate interval for mandatory calibration and the feasibility of alternative methods for verifying the accuracy of dose delivery.

Section 35.22 of 10 CFR (January 31, 1983) requires that the cobalt-60 units used for radiation therapy must have a monthly spot-check of the timer accuracy, congruence of the light and radiation fields, distance device accuracy, and output. Many times these spot-checks are performed by a physicist. If they are not performed by a physicist, the results must be reviewed by a qualified expert. There

are no requirements to spot-check the accuracy of the dose delivered to the patient by the operator of the cobalt-60 unit. Also, there is no provision, at any time, for an outside review of the accuracy of dose delivery.

Mailed reviews of institutional dose delivery have been conducted by many organizations. A mailed thermoluminescent dosimeter (TLD) package was chosen for use in many of these reviews. The International Atomic Energy Agency (IAEA), the Nuclear Regulatory Commission, the six Centers for Radiological Physics, the National Bureau of Standards, and the Radiologic Physics Center have found mailed TLD reviews to be a reliable and accurate method of dosimetry review (3,4,5)

To select the participants in this study, all U.S. Nuclear Regulatory Commission licensees operating cobalt-60 teletherapy sources for treatment of human patients in Illinois, Iowa, Minnesota and Wisconsin were contacted. Twenty hospitals from Illinois, Iowa, and Wisconsin were selected for participation in the study. Nine of the twenty hospitals chosen did not have a full-time physicist. The twenty hospitals selected were expected to benefit most from a mailed dosimetry review. Hospitals excluded were either participating in national protocols involving review by the Midwest Center for Radiological Physics (MWCRP) or were planning to decommission their cobalt-60 unit in the near future.

B. EXPERIMENTAL METHODS

1. Instrumentation

Radiation measurements at participating hospitals were made using a combined dosimetry package. This package basically consists of a diode radiation detection meter*, four thermoluminescent dosimeters, and Kodak XV-2 film.

*Model Vigilant II, manufactured by Microrad Technology, 201 Knollwood Street, Winston-Salem, NC, 27104

A 5 mm thick Lucite sheet was attached to the top surface of the diode meter. This sheet permitted the use of a 10cmx10cm field size and provided electron equilibrium build-up for cobalt-60 gamma rays. The Lucite was covered with a paper giving the irradiation instructions and an outline of the 10cmx10cm field (see Appendix 1). The digital meter display was purposely hidden by this sheet so that the user could not see the result.

The Lucite sheet extended approximately 5cm beyond the edge of the meter which allowed us to place the diode detectors at the center of the radiation field. The Lucite sheet has two milled recesses, each less than 1mm deep. One recess is located in the center of the field, directly above the two diodes. Three thermoluminescent dosimeter chips (Harshaw TLD-100) were placed in this center recess. One more TLD chip was placed in a recess approximately 13 cm from the center of the field to measure extraneous radiation that might be received during the shipment and handling of the package.

The dosimetry package was mounted in a padded box. The users were instructed to remove the top cover of the box and irradiate the instrument "in situ".

A 12cmx12cm piece of Kodak type XV-2 film in a light-tight package was placed between the Lucite sheet and the top of the diode meter case. Four lead spheres embedded at the corners of the 10cmx10cm outlined field (light field) were imaged on the film at the time of dose administration. This allowed evaluation of the light field-radiation field coincidence.

2. Calibration

When first received, each diode meter was tested according to our acceptance protocol (Appendix 2). The dosimetry package was irradiated to 1.50 Gy (150 rad) with the University of Wisconsin Accredited Dosimetry Calibration Laboratory cobalt-60 source (the output rate is traceable to NBS) using a 10cmx10cm field at 95cm SSD. The dose rate at this distance was about 0.3 Gy/min at the beginning of this study.

This dose rate is typical of calibration laboratories, though much less than that for radiation therapy installations. This dose rate caused problems noted in section 2a of part C. The exposure rate in air was measured with an ionization chamber calibrated at the National Bureau of Standards. This exposure rate in air was converted to an absorbed dose rate at 5mm (the depth of maximum dose (d_{max}) for cobalt-60 in muscle tissue). The time necessary to administer 1.50 Gy with this technique to a point 5mm deep in tissue was then calculated. The diode meter was irradiated for the calculated length of time and the meter was adjusted to display 0150. The diode meter was therefore calibrated to read directly in units of absorbed dose (rads) in tissue at d_{max} (see Appendix 3).

The reproducibility of the readings of the diode meter upon repeated identical exposures was not only within the manufacturer's stated precision (+/- 0.3% plus 1 digit), but, in fact, it usually gave identical readings.

The TLD chips were calibrated in a similar way. Four unexposed TLD chips were retained at our laboratory while the package was sent out to one of our participants. Upon return of the package, the TLD's and the film were replaced and the diode meter reading was recorded. The unit was then given a dose of 1.50 Gy. After twenty-four hours (see TLD calibration protocol: Appendix 3), the calibration TLD chips and those from the participating hospital were read out on the same TLD reader (Harshaw Model 3000). This provided a calibration of the TLD reader in TL counts per Gy each time TLD chips were read.

The calibration of the diode meter was checked each time the device returned from the field using the irradiation technique described above. If the display did not read 0150 after irradiation, the response was adjusted to read correctly before it was sent to the next institution. The discrepancy was usually no more than one unit. The dose rate was corrected weekly for the decay of the cobalt-60 source. This correction kept the error due to decay under 0.04%.

3. Procedure for interaction with participating hospitals

After the three dosimeter packages had been calibrated and tested for reproducibility with four repeat exposures, they were shipped to the participants via UPS. The instructions on the outside of the package indicated that the top of the shipping box should be opened and the dosimetry package exposed in the box at the normal treatment distance, to a dose of 1.50 Gy (150 rads). We experienced no trouble with the users understanding the instructions. In general, the package was returned promptly. Within a few days of the return of the package the results were sent to the participant. Since we did not want the participant to use the results as a calibration, we only indicated if the results were satisfactory ~~=~~ within 5% for the dose measurement and within 3mm for the light field/radiation field coincidence (see typical letters in Appendix 4). If the dose results were outside of 7%, the participant was informed by phone.

C. SUMMARY OF RESULTS

1. Tabulations

a. Diode Meter and TLD readings

The diode meter and TLD readings for Rounds 1, 2 and 3 are tabulated in Tables 1, 2, and 3. Results from the diode meter were generally in good agreement with those provided by the TL dosimeters throughout the entire study. Six times during the course of this study, the diode meter gave an extraordinarily low reading. These readings were excluded from Table 4. A proposed explanation for these low readings is discussed in section 2a of part C.

The criterion chosen for acceptable accuracy of radiation doses administered by the participating hospitals was 1.50 Gy at dmax in tissue, $\pm$ 5%. A dose of 142 rads was therefore unacceptably low while 158 rads was unacceptably high. Only two hospitals throughout the course of the study ever had both unacceptable diode meter and TLD

readings simultaneously. The ± 5% was based upon a doubling of the TLD precision (see section 2b of part C).

Hospital number 11 in Round One had diode and TLD readings which were both 1.42 Gy or less. A repeat dosimeter was sent to this hospital. The TLD reading was 1.46 Gy, in the acceptable range, while the diode reading, 0141, remained low. Three other hospitals in this round (4, 10, and 12) had either high or low TLD responses but the diode meter readings were acceptable in each case.

Hospital number 16 in Round Two had both diode meter and TLD readings of 1.42 Gy. Since this hospital had acceptable readings (1.54 and 1.48 Gy) in Round One, no repeat dosimeter was sent. (This hospital also had acceptable results in Round Three). Three hospitals in Round Two (8, 10 and 14) had low TLD readings with acceptable diode meter readings and another (18) had a high TLD reading with no valid diode meter reading. Four hospitals had abnormal diode meter readings for reasons explained in section 2a of part C.

Summaries of dose responses for all rounds are found in Tables 1-4. Tables 1, 2, and 3 list the results of the TLD and diode meter readings along with their percent difference with respect to the prescribed dose of 1.50 Gy (150 rad). These listings are followed by the percent difference between the TLD and diode meter readings. The average of the TLD and diode meter results is presented in Table 4 of this report for each hospital. A histogram of the diode meter and TLD readings is given in Figure 1.

Table 1. Results of TLD and Diode Meter Readings for Round One

Inst. Number	DATE	Diode (cGy)	% Diff.	TLD (cGy)	% DIFF	% Diff. Diode/TLD	LIGHT/RAD* COINCIDENCE
1	4/14/84	146	-3%	149.	-0.9%	1.8%	ACCEPTABLE
2	5/03/84	147	-2	148.	-1.	1	ACCEPTABLE
3	4/27/84	152	1	148.	-1.	-2.6	ACCEPTABLE
4	5/01/84	149	-1	158.	5.5	5.8	ACCEPTABLE
5	5/08/84	147	-2	153.	1.9	3.8	ACCEPTABLE
6	4/13/84	140	-1	145.	-3.	-1.9	ACCEPTABLE
7	5/02/84	147	-2	150.	0.05	2.1	ACCEPTABLE
8	5/09/84	146	-3	148.	-1.	1.5	ACCEPTABLE
9	5/18/84	146	-3	144.	-4.	-1.7	ACCEPTABLE
10	5/17/84	147	-2	142.	-5.	-3.7	ACCEPTABLE
11a	5/23/84	140	-7	142.	-5.	1.7	ACCEPTABLE
11b	6/22/84	141	-6	146.	-3.	3.5	ACCEPTABLE
12	5/30/84	146	-3	140.	-7.	-4.1	ACCEPTABLE
13	6/15/84	147	-2	151.	0.71	2.7	ACCEPTABLE
14	6/19/84	150	0	148.	-2.	-1.5	ACCEPTABLE
15	6/21/84	149	-.7	154.	3.	3.4	ACCEPTABLE
16	7/05/84	154	3	148.	-1.	-4	ACCEPTABLE
17	7/11/84	64	---	150.	0.17	---	ACCEPTABLE
18	7/09/84	147	-2	150.	0.03	2	ACCEPTABLE
19	7/17/84	145	-3.	143.	-4.	-1.1	ACCEPTABLE
20	7/23/84	148	-1	151.	0.79	2.1	ACCEPTABLE
AVERAGE:		147	-2.0	148.	-1.0	0.54	
Std. Dev.		3.13		4.37			
% std dev		2.1		3.0			

*Acceptable light and radiation field coincidence was +/- 3 mm

Table 2. Results of TLD and Diode Meter Readings for Round Two

Inst. Number	DATE	Diode (cGy)	% Diff.	TLD (cGy)	% DIFF	% Diff. Diode/TLD	LIGHT/RAD* COINCIDENCE
1	7/31/84	146	-3.	143.	-5.	-2.2	ACCEPTABLE
2	8/9/84	148	-1.	143.	-5.	-3.5	NOT ACCEPT.
3	7/30/84	148	-1.	147.	-2.	-0.4	ACCEPTABLE
4	9/7/84	149	-0.7	153.	1.7	2.4	ACCEPTABLE
5	8/8/84	50	---	146.	-2.	----	ACCEPTABLE
6	7/20/84	146	-3.	146.	-3.	0.2	ACCEPTABLE
7	7/31/84	145	-3.	146.	-3.	0.6	ACCEPTABLE
8	8/18/84	148	-1.	142.	-6.	-4.6	ACCEPTABLE
9	9/5/84	147	-2.	148.	-1.	0.7	ACCEPTABLE
10	8/27/84	148	-1.	142.	-6.	-4.3	ACCEPTABLE
11	9/13/84	75	---	145.	-3.	---	ACCEPTABLE
12	9/13/84	147	-2.	146.	-3.	-0.9	ACCEPTABLE
13	9/13/84	147	-2.	----	---	----	ACCEPTABLE
14	9/25/84	152	1.3	142.	-6.	-7.1	ACCEPTABLE
15	9/24/84	153	2.0	149.	-0.9	-2.9	ACCEPTABLE
16	9/25/84	142	-6.	142.	-6.	0.0	ACCEPTABLE
17	10/10/84	97	---	148.	-1.	----	ACCEPTABLE
18	10/9/84	0	---	159.	5.7	----	ACCEPTABLE
19	10/5/84	146	-3.	143.	-5.	-2.4	ACCEPTABLE
20	10/15/84	150	0	147.	-2.	-1.9	ACCEPTABLE
AVERAGE:		148	-2.	146	-3	-1.4	
STD DEV:		2.6		4.3			
%std dev:		1.8%		2.9%			

*Acceptable light and radiation field coincidence was +/- 3 mm

Table 3. Results of TLD and Diode Meter Readings for Round Three

Inst. Number	DATE	Diode (cGy)	% Diff.	TLD (cGy)	% DIFF	% Diff. Diode/TLD	LIGHT/RAD* COINCIDENCE
1	10/19/84	147	-2.	144.	-4.	-1.9	ACCEPTABLE
2	10/24/84	147	-2.	142.	-5.	-3.3	NOT ACCEPT.
3	10/25/84	151	0.7	148.	-1.	-2.2	ACCEPTABLE
4	1/5/85	148	-1.	149.	-0.4	0.9	ACCEPTABLE
5	11/5/84	149	-0.7	158.	4.9	5.5	ACCEPTABLE
6	11/6/84	147	-2.	149.	-0.4	1.6	ACCEPTABLE
7	10/24/84	---	---	145.	-3.	----	ACCEPTABLE
8	11/13/84	---	---	148.	-1.	----	ACCEPTABLE
9	12/7/84	147	-2.	138.	----	----	ACCEPTABLE
10	11/14/84	146	-3.	146.	-3.	0.1	ACCEPTABLE
11	11/21/84	146	-3.	149.	-0.8	1.9	ACCEPTABLE
12	12/7/84	149	-0.7	148.	-1.	-0.4	ACCEPTABLE
13	12/6/84	153	2.0	156.	3.8	1.9	ACCEPTABLE
14	12/18/84	154	2.6	147.	-2.	-5.1	ACCEPTABLE
15	12/12/84	153	2.0	152.	1.5	-0.4	ACCEPTABLE
16	12/13/84	145	-3.	150.	-0.2	3.1	ACCEPTABLE
17	12/19/84	152	1.3	154.	2.8	1.5	ACCEPTABLE
18	12/20/84	146	-3.	150.	-0.2	2.5	ACCEPTABLE
19	12/31/84	145	-3.	144.	-4.	-0.7	ACCEPTABLE
20	12/28/84	154	2.6	151.	0.6	-2.1	ACCEPTABLE
AVERAGE:		149	-0.8	149.	-0.8	0.2	
STD DEV:		3.2		4.1			
% std dev:		2.1%		2.8%			

*Acceptable light and radiation field coincidence was +/- 3 mm

Table 4. Average of TLD and Diode Meter Readings by Hospital

Hospital	Round 1	Round 2	Round 3	Mean	% S.D.
1	147.5	144.5	145.5	145.8	0.9%
2	147.5	145.5	144.5	145.8	0.9%
3	150.0	147.5	149.5	149.0	0.7%
4	153.5	151.0	148.7	151.1	1.6%
5	150.0	(146.0)	153.5	149.8	2.0%
6	146.5	146.0	148.0	146.8	0.6%
7	148.5	145.5	(145.0)	146.3	1.1%
8	147.0	145.0	(148.0)	146.7	1.0%
9	145.0	147.5	[147.0]	146.5	0.7%
10	144.5	145.0	146.0	145.2	0.4%
11	143.5	(145.0)	147.5	145.3	1.1%
12	143.0	146.5	148.5	146.0	1.6%
13	149.0	[147.0]	154.5	150.2	2.1%
14	149.0	147.0	150.3	148.8	1.1%
15	151.5	151.0	152.5	151.7	0.4%
16	151.0	142.0	147.5	146.8	2.5%
17	(150.0)	(148.0)	153.2	150.4	1.7%
18	148.5	159.0	147.9	151.8	4.1%
19	144.0	144.5	144.5	144.3	0.0%
20	149.5	148.5	152.4	150.1	1.3%
Mean	148.95	147.1	148.7	147.9	1.3%

Parentheses indicate a reading based on TLD results alone, while brackets indicate a reading based on diode meter reading alone.

b. Light Field and Radiation Field Coincidence

When the dosimetry package was returned from a hospital, the coincidence of the radiation field with the light field was determined. Two calibration films (from the same batch as that sent to the hospital) were exposed (with buildup) to 0.75 Gy and 1.50 Gy. The center optical density (COD) of each calibration film and of the film

exposed by the hospital was read. If the COD of the film from the dosimetry package closely matched that of the 1.50 Gy calibration film, we knew that the dose delivered was approximately 1.50 Gy. Since the 50% isodose line was used to define the edge of the radiation field, the COD of the 0.75 Gy film provided us with the density at the radiation field edge. Points with this density were found on each edge of the radiation field on the dosimetry film. A line connecting these points was drawn along each side. Next, a line was drawn through the images of the four lead spheres at the corners of the outlined 10cmx10cm field. The separation between the lines on each edge determined the deviation between the radiation field and light field.

The maximum deviation between fields is listed for each side in the following table. A plus sign indicates that the radiation field was smaller than the light field.

Table 5. Light Field and Radiation Field Coincidence

	Maximum Deviation			
	Gantry	Left	Right	Foot
Round One	+/- 2.5 mm	+2.0 mm	+2.0 mm	-3.0 mm
Round Two	+ 4.0	+2.5	+2.0	-3.5
Round Three	- 4.0	+2.0	-3.0	-2.0
Average Dev :	+ 0.3 mm	+0.1 mm	+0.2 mm	-0.4 mm

Only one hospital had a problem with coincidence between the two fields. The first result for this hospital was within the 3 mm limit. However, the second and third results were not acceptable, though the third results were better than the second. On the other hand, only one hospital had a measurement with a deviation of less than 1mm on any side.

c. Turn Around Time

Turn around time is the time taken for a dosimetry package to leave and return to the lab. The turn around time was important to the investigation as it determined the rate at which information could be gathered. The mean turn around time for the twenty hospitals in Round One was 10.3 days. The mean turn around time was 8.7 days for Round Two and 9.3 days for Round Three. However, the turn around times from two hospitals with very long return times (30 days) were excluded from the average for Round Two. The mean turn around times were satisfactory for the study.

The turn around time was approximately one month for the two exceptional cases in Round Two. In one case, the registered nurse in charge did not know how to do the irradiation and she was waiting for the radiotherapist to do it. At this hospital the radiotherapist did all the calculations and performed all the irradiations. For the second long turn around time we received no satisfactory explanation for the delay. No delay problems were experienced in Round Three.

2. Discussion

a. Reliability of instrumentation

Calibration of the diode meter was, in general, accomplished with little difficulty. The manufacturer stated that the diode detectors were designed to zero the display and begin to accumulate a new reading when exposed to radiation above a threshold dose rate of 0.06 Gy/min. This threshold can be changed by adjustment of a potentiometer inside the case. In our situation, none of the three meters would respond to the relatively low dose rate produced by the UW cobalt-60 source (approximately 0.3 Gy/min) when they were received. After adjustment of the potentiometer, each device successfully passed our acceptance procedure (see Appendix 2). It was never determined why the devices would not respond initially to a dose rate well above the manufacturer's stated threshold. This presumably would not be a problem at

a clinical institution, which typically has a dose rate of 1.0 Gy/min or more.

An abnormally low reading (0064) was noted on the display of one of the diode meter units upon return from hospital 17 in the first round. Since the TLD reading was 1.50 Gy there was no initial explanation for this discrepancy. Irradiation of the device at our facility, to 1.50 Gy produced a reading of 0150, exactly as it had read before going out. The same device worked properly on all subsequent trials. However, another unit had a reading of 0050 after return from hospital 5 in round two of the trial. The corresponding TLD reading was 1.46 Gy. This device again worked properly in our laboratory and gave acceptable readings in its next two trials, but then displayed a reading of 0075 after return from hospital 11 in round two (the TLD result for this trial was 1.45 Gy). The manufacturer pointed out that a likely explanation for these low readings is fractional delivery of the dose. Therefore, the diode meter would only display the last fraction of the dose. The physicist at hospital 11 was contacted and he confirmed that the exposure was made in two fractions, thus verifying the manufacturer's explanation for that case.

An additional problem came up in round two when a diode meter returned from hospital 2. When this meter was irradiated by the UW cobalt-60 source the display would not change. The possibility of dose rate dependency was examined and the SSD was changed. However, the display remained the same. The unit was opened and the battery connection was found to be bad. Also, the battery voltages were measured, and both were less than 8.2 volts, which might produce unreliable operation. A new battery measures 9.2 volts.

Another problem was noted with the diode meter. This occurred in round two and was not resolved until after it reoccurred in Round Three. After irradiation, in Round Two by hospital 18, the diode display was 0000; however, the TLD reading was 1.59 Gy. The TLD reading was therefore unacceptably high and the diode meter reading was not valid. The hospital was contacted regarding the TLD dose of 1.59

Gy. It was discovered that an error had been made in calculating the exposure time. Each hospital reports the time set on the cobalt-60 unit. It could be seen that the timer setting for this exposure was not what one would expect, based on the timer setting given for the exposure 60 days before. This indicates that problems with proper chart usage can be detected using this dosimetry system. However, the diode meter reading still required explanation. Although this unit returned with a display of 0000, when it was irradiated to 1.50 Gy at UW, the display read 0150. The same results (0000 display) were obtained from the next hospital to use this same diode meter. The manufacturer was consulted, and they stated that a poor electrical connection may be the problem. Batteries in all three devices were securely taped into place and no further problems were experienced.

We found unsecure battery connections to be the source of many of the problems we experienced with the diode meter. We also found that the two mercury batteries used in the diode meter had to be changed every three months. The device was not equipped with an ON/OFF switch to conserve the batteries. We understand from the manufacturer that the new model can use less expensive alkaline batteries and is equipped with an ON/OFF switch so that the batteries can be conserved when the device is not used.

The manufacturer of the diode meter did not provide a circuit diagram and the identification of several critical components had been intentionally removed, so that repair of the unit by the user is difficult if not impossible.

b. Sources of error

TLD's have been used for almost two decades for mailed dosimetry systems (5). The accuracy is typically 2 or 3% if care is taken in the calibration of the TLD's. Since there is some variation from one TLD chip to another, we kept track of each individual chip in order to improve our accuracy. In addition, we averaged the results of the three center TLD's in each kit. This average was then adjusted to

account for the extraneous radiation reading given by the fourth chip. Typically, this extraneous radiation was 0.014 Gy (1.4 rad).

The TLD and diode readings agreed with each other to within 2.5% for 85% of the readings, (excluding the diode meter and TLD readings that were obviously in error). The diode device had not been previously used for field measurements. In general, it performed well, with the exception of the problems noted above.

The diode meter has demonstrated a high reproducibility in laboratory measurements (1,2). The problems we encountered with the unit were not reported in that article. (The first author of the article is also the president of the company that manufactures the unit.)

D. COST-BENEFIT ANALYSIS

The cost of this mailed dosimetry service is estimated to be $50 per unit surveyed. This allows $10.00 for overhead.

The cost of the biennial calibration of an ionization chamber is typically $400. If the calibration was performed every four years instead of every two years this would produce a savings of $100 per year. An annual mailed dosimetry check would thus save $150/year for the two year period and $50/year for the four year period. The dollar benefit of such a quality assurance (QA) service is difficult to assess. The service would greatly reduce the probability of serious errors in dose delivery. If such errors occur, the patient may suffer from severe complications due to an over-exposure, or an increased probability of recurrence of the cancer if there is an under-treatment.

The service can be provided without the use of the TLD's, which would result in a $15 savings per unit surveyed (see Appendix 5). If we assume that a significant error is detected 5% of the time, the approximate cost of detecting such an error is $1000 (20 hospitals/one

detection x $50.00 = $1000.00). If a medical center used the service on a monthly basis to fulfill their need for a spot-check of output and light/radiation field coincidence, it would cost about $600.00 a year. This check should be reviewed by a qualified expert (thus following 10 CFR Part 35). In a typical therapy center, subscribing to this QA service at this price would be a small percent of the annual budget.

E. CONCLUSIONS

We conclude that a mailed dosimetry service using a simple dosimetry package with an integrating diode dosimeter, four TLD's, and a film to measure the light field and radiation field coincidence is a practical means by which the practice of radiation therapy with cobalt-60 or other therapy units can be improved at a very reasonable cost. Such a service would permit calibrations of the ion chamber to be performed every four years. We further conclude that such a QA service is cost effective.

F. RECOMMENDATIONS

As a result of this research we make the following recommendations:

1. We recommend an outside mailed dosimetry review of cobalt-60 teletherapy units, independent of the time between ion chamber calibrations. We recommend such a review at three month intervals for hospitals which have a full-time physicist and at monthly intervals for other hospitals. A mailed dosimetry review consists of a test package which measures the administered radiation dose and the coincidence of the light field with the radiation field. Suggested criteria for acceptable results are $\pm$ 5% of the stated dose and coincidence of the light and radiation fields within $\pm$ 3mm. Results of these measurements should be reviewed by a qualified medical physicist.

2. We recommend that the Nuclear Regulatory Commission encourage the establishment of Accredited Regional Radiation Centers to provide such

outside mailed dosimetry reviews as a form of Quality Assurance for cobalt-60 teletherapy units.

3. We recommend that the Nuclear Regulatory Commission encourage licensees of cobalt-60 teletherapy units that are treating patients to subscribe to such an outside mailed dosimetry service when it becomes available.

4. We recommend that Centers providing such a mailed dosimetry review service be accredited and regularly reviewed by the American Association of Physicists in Medicine.

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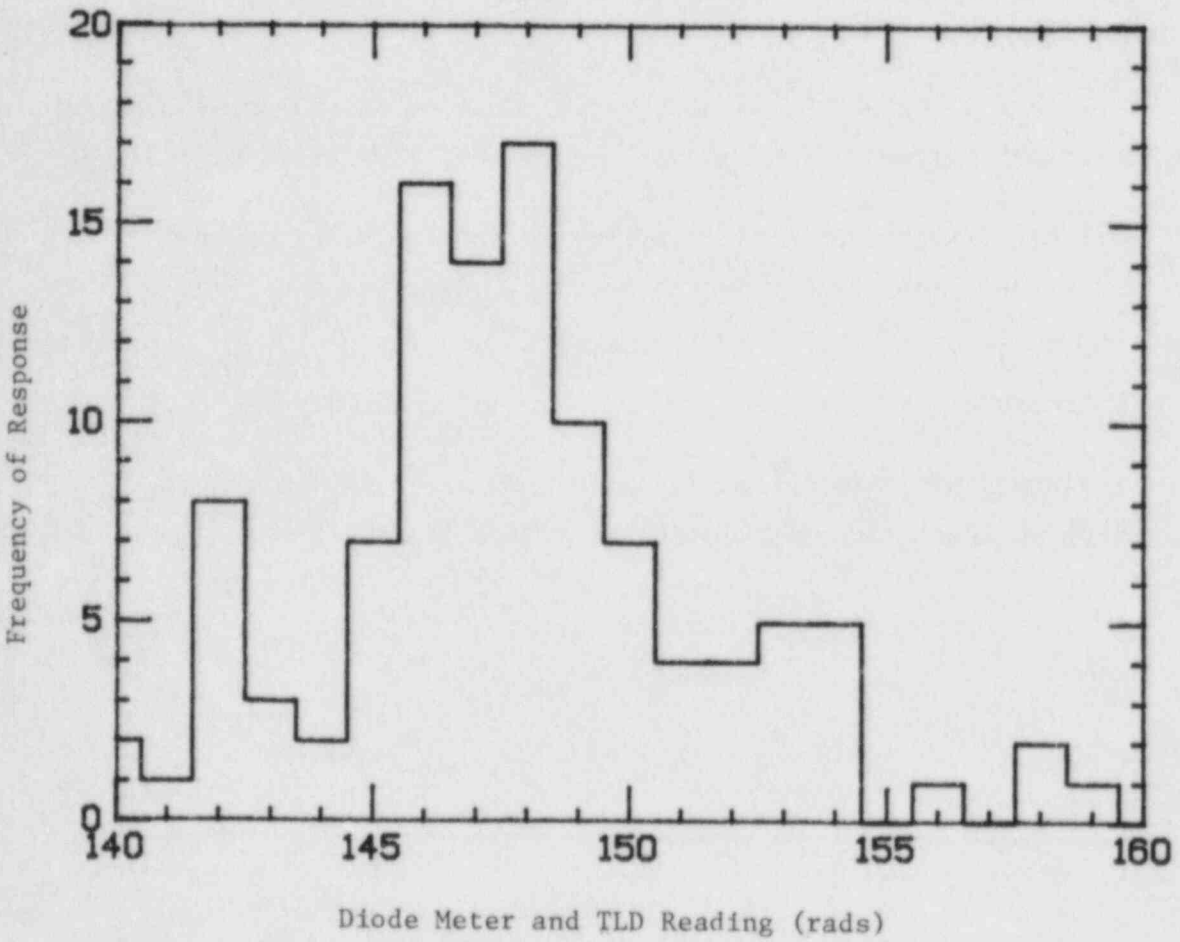
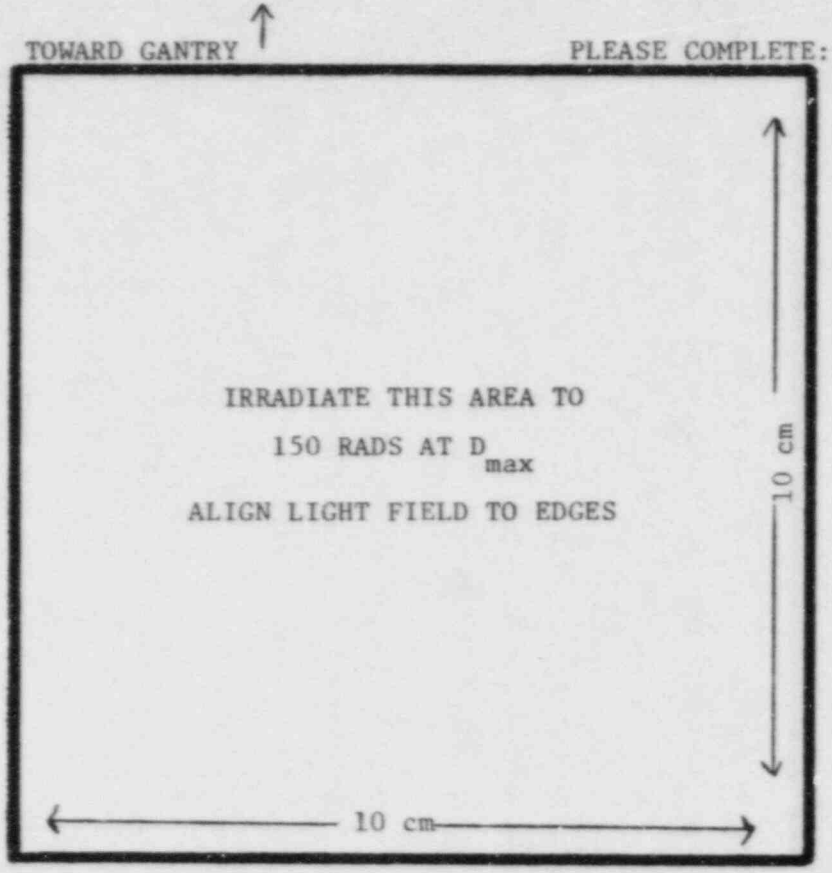
Related Literature:

Rozenfeld M, Jette D. Quality assurance of radiation dosage: usefulness of redundacy. Radiology 1984; 150:241.

Figure 1: Histogram of Dosimetry Results
for All Three Rounds





PLEASE COMPLETE:→

DATE OF EXPOSURE: _____

MADE BY: _____ (PLEASE PRINT)

_____cm SSD OR _____cm SAD

TIMER SETTING: _____

FIELD SIZE INDICATED ON UNIT:

_____.___ cm X _____.___ cm

INSTRUCTIONS:

1. Place on treatment couch with top edge toward gantry
2. Set normal SSD to surface or normal SAD to D_{max}
3. Align light field localizer with outline (10 x 10)cm
4. Give 150 rad (1.5 Gy) at D_{max} (as in phantom)
5. Fill in the blanks above
6. Reverse card on shipping container to show address shown below and mail promptly via UPS
7. If you have any questions call (608)262-6320
   Dept. of Medical Physics
   UW Calibration Service
   Rm. 1530 1300 University Ave.
   University of Wisconsin
   Madison, WI 53706

APPENDIX 2

PROTOCOL FOR

ACCEPTANCE AND QUALITY ASSURANCE

OF MICRORAD VIGILANT II DIODE DOSIMETERS

1. Upon arrival after purchase, the units are checked for exterior damage. NOTE: The display should be ON at all times.

2. The unit is placed on the treatment table of the Co-60 unit and given four sequential exposures of 150 R. The readings are recorded after each exposure. The mean of the four readings must be within 1% of the given exposure and the standard deviation of the four exposures must be less than or equal to 1%.

3. The unit is given a series of exposures at 50, 100, and 200 R. For a least squares fit, the resulting intercept must be less than +/- 1.0 R, and the slope must be within 0.01 of unity. The correlation coefficient should be 0.99 or greater.

4. During the initial acceptance testing the unit is stored for seven days after the last reading without further handling. The reading at the end of seven days should be identical to the last reading.

5. During the initial acceptance testing, one unit is randomly selected and stored for at least 15 days after its final exposure to see if the reading changes.

6. Each unit must be inspected for damage each time it is returned from one of the cooperating institutions. The reading should be recorded and the acceptance procedure in step (2) must be repeated.

APPENDIX 3

Protocol for TLD Measurements for Monitoring of Therapy Units

I. Description of Dosimeter

The dosimeter package consists of a Microrad Technology Vigilant II diode radiation detector covered with a 5mm thick sheet of Lucite. Underneath the Lucite are three TLD chips* and a piece of photographic film. A slot just large enough to hold three TLD chips is milled in the bottom surface of the Lucite directly in the center of the 10cm x 10cm field. The top layer of the package is thus thick enough to provide adequate buildup for Co-60 photons. Holes are drilled at the corners of the Lucite to bolt it to the Vigilant. Small holes packed with lead shot are located at the corners of the 10cm x 10cm field to check the light-radiation field coincidence. Kodak X-OMAT V film is sandwiched between the bottom of the Lucite and the top of the Vigilant meter. The films are trimmed to the appropriate size and sealed with black tape. The chips are located between the film and the Lucite.

II. Initial Calibration of the TLD chips

1) When TLD-100 chips are received, they are assigned to a unique spot in an aluminum tray having 100 individual spaces. The chips remain in this tray for the remainder of their useful life, unless they are being processed or traveling. An aluminum cover is put on the tray so the chips remain in fixed positions.

2) The TLD/aluminum tray combination is put in a furnace that has equilibrated to 400°C for at least 1 hour. The TLDs are annealed at

*Harshaw LiF (TLD-100) ribbons are used throughout this procedure (3.2 mm x 3.2 mm x 0.9 mm).

400°C for 1 hour. After removal the tray combination is allowed to cool for at least 60 minutes on a lead brick.

3) The TLD aluminum tray combination is then put into an 80°C oven for 24 hours. Again the chips are allowed to cool for 60 min on a lead brick after removal from the oven.

4) For exposure calibration of the tray, the TLDs are put in a Lucite tray which has a number of 1 mm spaces milled in it similar to the aluminum tray combination. In this way, the chips retain their unique assignment. A buildup layer of 5 mm is put on top of this Lucite tray and the chips are irradiated to 150 rads (1.5 Gy) using the cobalt-60 machine.

5) All 100 chips are read at least 18 hours after irradiation.

6) The average of the TLD readings is determined and a correction factor (in absorbed dose per TL count) to this average is thus determined for each of the chips.

7) Steps 2-6 are repeated.

8) Since there is a variation in TL response for each chip a correction factor for each chip is determined by normalizing the average reading of the two trials. Each reading in the second trial is therefore multiplied by the ratio of the average reading of all chips in the first trial to the average reading of the same chips in the second trial. This normalizes the results. Each TLD chip now has a normalized reading from the second trial and a reading from the first trial. The correction factor for an individual chip is therefore equal to the normalized average reading divided by the average of the reading from trial one and the normalized reading from trial two:

$$\text{Eq. (1)} \quad C.F._n = \frac{X_{ave}}{(1/2) * (X_n + Y_n * \frac{X_{ave}}{Y_{ave}})}$$

where $C.F._n$ is the correction factor for the n-th chip, X_{ave} and Y_{ave} are the average readings of all chips in trial one and trial two, respectively, and X_n and Y_n are the individual readings of the n-th chip in the first and second trials. This calculation is contained in the computer program THERAPY3.

9) The chip is accepted for use if the standard deviation of the reading from trial one and the normalized reading from trial two is less than 7%.

III. Calibration of the Vigilant II Meter and TLD Chips

1) The diode meter and TLD chips are calibrated to read directly in rads (Gy) in water at D_{max} for Co-60 in a semi-infinite water phantom.

2) The exposure rate in air (R/min) (corrected for timer error) at 95cm SSD for a 10cm x 10cm field on the UW Medical Physics Picker C10,000 Co-60 source is determined using the Exradin A1 chamber calibrated by the National Bureau of Standards.

3) The absorbed dose rate in water at D_{max} is calculated as follows:

$$\text{Eq. (2)} \quad D = X * 0.985 * 0.957 * 1.035 * \frac{(95)^2}{(95.5)^2} = 0.965 * X$$

where X is the exposure rate determined in step (2), 0.985 is the displacement correction factor, 0.957 is the conversion factor from Roentgens to rads in muscle (for Co-60) and 1.035 is the backscatter factor in water for a $10x10cm^2$ Co-60 field at 100cm SSD. The inverse square correction must be made to account for the measurement in air being made at 95cm SSD and not at D_{max}.

4) The absorbed dose rate is to be corrected every week according to the table provided by the Chief Physicist.

5) The Vigilant II is to be exposed with the top surface of the Lucite

build-up sheet at 95cm SSD and the 10cm x 10cm field coincident with the field markings on the top surface.

6) The response of the Vigilant II is adjusted to match that calculated for a 5 minute reading (approximately 150 rads, or 1.5 Gy).

7) The response of the Vigilant II meter during the calibration exposure must be 150 +/- 1 rad (1.50 Gy). If the meter reading is outside these limits, its response must be re-adjusted to be correct.

IV. Preparation of the Cassette

1) Just before shipment to a participating institution, a group of TLD chips is annealed (as in Part II).

2) The TLD chips are removed from the aluminum trays and packaged in small plastic packets labeled with the tray number and position number of the tray.

3) Three TLD chips are placed near the center of the 10cm x 10cm radiation field marked on the top surface of the package and one is placed well out of the radiation field to measure any background radiation.

4) The instructions for irradiation of the device and the field markings are on the face of the device.

5) The dosimetry package will be sent three times to each individual hospital.

6) The device is packaged in a box that is returnable and a return address label is enclosed. Irradiation is to be performed without removing the unit from the lower half of the shipping container.

V. Determination of Given Dose

1) When the dosimeter is returned to the University of Wisconsin the reading on the diode meter (calibrated in dose as described above) is read. The TLD chips are then read together with the companion

calibration chips. The calibration factor obtained from the calibration chips and the appropriate correction factors are then applied to determine the dose for each dosimeter received.

2) The films are processed and the location of the lead dots relative to the radiation field is used to check the coincidence of the light field at the participating institution with their radiation field. The size of the radiation field is determined from prior calibration of the optical density of Kodak X-OMAT V film exposed at 150 and 75 rads (1.50 and 0.75 Gy). The optical density of the film is measured with a densitometer and the position of the 75 rad (0.75 Gy) isodose line is taken as the border of the radiation field.

3) The data is recorded in a laboratory notebook, including the TLD readings, diode reading and the film readings. The ratio of the TLD dose to 150 rads (1.5 Gy) is also recorded.

4) If the average reading of the TLDs or the reading of tne diode meter is found to be outside of +/- 5% of 150 rads (1.5 Gy), a repeat dosimeter is sent. The +/- 5% criterion was selected based on the doubling of the 2-3% uncertainty of the TLD response. If the repeat dosimeter shows a similar discrepancy the physicist will be encouraged to check the machine calibration with the institution's ion chamber. If a discrepancy of 7% or greater is found, the physicist is immediately contacted.

APPENDIX 4

DEPARTMENT OF MEDICAL PHYSICS

1530 Medical Sciences Center
1300 University Avenue
Madison, Wisconsin 53706
Phone: 608-262-2170

December 27, 1984

Radiation Therapy Department
Attn. Radiotherapy Physicist

Dear Sir:

Thank you for participating in the final round of our mailed dosimetry study. We appreciate your prompt response. It will help us gather more information.

We are happy to report that your exposure made on December 14, 1984 was within 5% of the "prescribed dose". The radiation field-light field coincidence was within the 3 mm variance allowed.

If you have any questions, please feel free to contact Julie Price at the address above or by phone at (608) 262-6320.

Sincerely yours,

John Cameron, Ph.D.
Professor and Chairman

UNIVERSITY OF WISCONSIN MEDICAL SCHOOL

DEPARTMENT OF MEDICAL PHYSICS

1530 Medical Sciences Center
1300 University Avenue
Madison, Wisconsin 53706
Phone: 608-262-2170

December 27, 1984

Radiation Therapy Department
Attn. Radiotherapy Physicist

Dear Sir:

Thank you for participating in the final round of our mailed dosimetry study. We appreciate your prompt response. It will help us gather more information.

We are happy to report that your exposure made on December 14, 1984 was within 5% of the "prescribed dose". The radiation field-light field coincidence was not within the 3 mm variance allowed:

Gantry:	(+/-)___mm
Left:	(+/-)___mm
Right:	(+/-)___mm
Foot:	(+/-)___mm

If you have any questions, please feel free to contact Julie Price at the address above or by phone at (608) 262-6320.

Sincerely yours,

John Cameron, Ph.D.
Professor and Chairman

UNIVERSITY OF WISCONSIN MEDICAL SCHOOL

DEPARTMENT OF MEDICAL PHYSICS

1530 Medical Sciences Center
1300 University Avenue
Madison, Wisconsin 53706
Phone: 608-262-2170

December 27, 1984

Radiation Therapy Department
Attn. Chief Radiotherapist

Dear Sir:

Thank you for participating in the final round of our mailed dosimetry study. We appreciate your prompt response. It will help us gather more information.

The exposure made on December 14, 1984 was not within 5% of the "prescribed dose". We contacted , the consulting physicist for the hospital. He contacted the individual that actually made the exposure. It was concluded that an error in had been made. If time allows, we will send the cassette back for a new measurement. The radiation field-light field coincidence was within the 3 mm variance allowed.

If you have any questions, please feel free to contact Julie Price at the address above or by phone at (608) 262-6320.

Sincerely yours,

John Cameron, Ph.D.
Professor and Chairman

APPENDIX 5

University of Wisconsin

Cost Analysis For Mailed QA for Radiation Therapy Units

Cost of Materials:

I	Cost of the Cassette, Modifications, and Batteries	$950.00
	A) Estimated lifetime of cassette = 190 cycles	
	B) Cost per cycle	$5.00
II	TLD Cost:	
	A) Purchase and initial calibration of 100 TLD chips	$235.00
	B) Prorated cost of TLDs per cycle (Estimated average life of each chip is 3 years 4 needed per cycle)	$ 0.25
III	Operating Costs per Cycle:	
	A) Cassette preparation, log in, and check of diode calibration	$10.00
	B) TLD readout	15.00
	C) Film evaluation	5.00
	E) Calculations: Computer time and Report preparation	10.00
	Total Cost per Use:	$40.00
	Overhead	$10.00
	Charge to user	$50.00

NRC FORM 335 (2.84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

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5. AUTHOR(S)
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U.S. Nuclear Regulatory Commission
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12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

The research described in this report was performed to investigate the feasibility of a mailed dosimetry system as an alternative method of achieving the goals of the present U.S. Nuclear Regulatory Commission requirement that ionization chambers used for calibration of cobalt-60 teletherapy units be calibrated every two years. Both thermoluminescent dosimeters (TLD's) and a diode detector unit were used in this study. A total of 20 hospitals in the states of Illinois, Iowa and Wisconsin participated in a program in which this dosimetry package was sent to each institution on three separate occasions. The physicist, physician or chief technologist was asked to deliver 1.50 Gray (150 rads) to the device, assuming the device was equivalent in radiation absorption characteristics to human tissue. A treatment field size of 10cm by 10cm was chosen and the institution was requested to use their clinical source-to-surface distance. The accuracy of the beam localization as indicated by the coincidence of the light field with the radiation field was measured as well. The criterion for accuracy of dose delivery was ±5% and the criterion for light field and radiation field coincidence was ±3.0mm. Only two hospitals during the course of the study had both unacceptable diode meter and TLD readings simultaneously. Only one hospital had a disagreement of more than 3mm between the light field and the radiation field. It is recommended that such a mailed dosimetry package be considered as an alternative to the present NRC requirement for biennial calibration of ionization chambers used to calibrate cobalt-60 teletherapy sources.

14. DOCUMENT ANALYSIS - a. KEYWORDS/DESCRIPTORS

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Thermoluminescent dosimeters
Diode radiation detectors

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WASHINGTON, D.C. 20555

OF BIENNIAL CALIBRATION OF IONIZATION CHAMBERS