September 21, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
CAROLINA POWER & LIGHT COMPANY and NORTH CAROLINA EASTERN MUNICIPAL POWER AGENCY	)	Docket No. 50-400 OL
	)	
(Shearon Harris Nuclear Power Plant)	)	

APPLICANTS' TESTIMONY OF STEPHEN A. BROWNE IN RESPONSE TO JOINT CONTENTION IV (THERMOLUMINESCENT DOSIMETERS)

Q.1 Please state your name, address, present occupation and employer.

A.1 My name is Stephen A. Browne. My business address is: Shearon Harris Energy & Environmental Center, Route 1, Box 327, New Hill, North Carolina 27562. I am employed by Carolina Power & Light Company ("CP&L") as Project Specialist - Health Physics. In this position I am responsible for the technical direction of the personnel dosimetry program for all CP&L nuclear plants.

Q.2 State your educational background and professional work experience.

A.2 I have a Bachelor of Science degree in Physics from Union College. I received a Masters of Science degree in Environmental Health Engineering from Northwestern University. A summary of my professional experience and qualifications is contained in Attachment A to this testimony. For the last eight years I have been directly involved with the supervision and direction of dosimetry programs using thermoluminescent dosimeter ("TLD") systems manufactured by Harshaw, Teledyne and Panasonic, the major manufacturers of TLD systems used in the United States today. Recently I have been a consultant to the National Bureau of Standards ("NBS") as a technical expert in assessing and evaluating personnel radiation dosimetry processors under the National Voluntary Laboratory Accreditation Program ("NVLAP").

Q.3 Describe the major responsibilities of your position at CP&L.

A.3 In my current position, I am responsible for technical and quality assurance management of the CP&L dosimetry program. The scope of these responsibilities includes supervision of the following types of activities: preparation and processing of TLD badges, data processing, establishment of methods and procedures for all phases of dosimetry operations, calibration and maintenance of dosimetry equipment, establishment of quality assurance standards, performance of quality control inspections and checks, training and qualification of dosimetry staff, performance of tests, development of new methods and systems, and maintenance of official personnel exposure history records.

Q.4 What is the purpose of your testimony?

A.4 The purpose of my testimony is to address the remaining issue of Joint Contention IV which can be stated as follows: Can the TLDs and measuring equipment and processes to be used at the Harris Plant measure occupational radiation doses with sufficient accuracy to comply with NRC regulations? (Tr. 2218, August 10, 1984 Conference Call).

My testimony demonstrates that the TLDs to be used at the Harris Plant and CP&L's processing techniques are sufficiently accurate to comply with the American National Standards Institute ("ANSI") standard (which has been proposed as an NRC rule on TLD accuracy), the International Commission on Radiological

Protection ("ICRP") standard, as well as the interpretation of the current regulatory standard suggested by the Board. Therefore, there is no merit to the remaining issue in Joint Contention IV.

Q.5 How is your testimony organized?

A.5 First I will describe the manner in which TLDs are to be used and processed at the Harris Plant. I then will explain the standards for TLD accuracy which have been proposed by organizations involved with radiation protection and which have been suggested by the Board and demonstrate that CP&L's program is consistent with all such standards. Finally, I will explain CP&L's program for maintaining the accuracy of its TLD processing system and mitigating the most frequently observed causes of inaccuracy.

Q.6 What are TLDs?

A.6 "TLD" stands for thermoluminescent dosimeter, which is a device used for measuring exposure to radiation. When a TLD is irradiated by ionizing radiation, some energy is absorbed and stored. If the TLD subsequently is heated, some of the stored energy is released as light which can be detected and measured. The quantity of light released is proportional to the dose received by the individual wearing the TLD.

Q.7 What type of TLDs will be used at the Harris Plant?

A.7 We plan to use Model UD-802 AQ TLDs manufactured by Panasonic. The manufacturer's technical specifications of those TLDs are set forth in Applicants' Exhibit __________.

Q.8 How will TLDs be used at the Harris Plant?

A.8 TLDs will be used to perform routine monitoring of personnel. The objective of routine monitoring is to assess the cumulative dose to individuals for official exposure record-keeping purposes.

Q.9 Why are TLDs the chosen method for routine monitoring?

A.9 TLDs are nearly ideal for routine monitoring because they are rugged, reliable, accurate, and sensitive. TLDs are capable of measuring the dose from the types and energies of radiation which represent significant external exposure hazards in nuclear power plants. For instance, for beta radiation, the TLDs proposed for the Harris Plant are capable of measuring dose over the energy range from about 0.1 to 2.3 MeV. Betas below 0.1 MeV are too weak to be a significant external hazard, while betas above 2.3 MeV are very rare. For gamma radiation, the TLDs have a usable energy range from about 40 keV to 7 Mev. Gammas above this range are rare and gammas below this range contribute relatively little to the total dose in nuclear power plants. With appropriate calibration, the TLD also can be used for neutron monitoring in the event that such monitoring is necessary.

Q.10 When are TLDs worn?

A.10 TLDs are worn continuously by individuals while working in the radiologically controlled areas of nuclear power plants.

Q.11 How frequently are TLDs processed?

A.11 TLDs are processed to obtain official dose readings at least monthly. Some TLDs are processed more frequently for exposure control purposes.

Q.12 Are there relevant standards for the accuracy required in routine monitoring?

A.12 Yes. The International Commission on Radiation Units and Measurements ("ICRU"), the ICRP, and the National Council for Radiation Protection and Measurements ("NCRP") have addressed the issue of accuracy for individual monitoring and published recommendations in ICRU Report 20, ICRP Report 35 (which superceded ICRP Report 12) and NCRP Report 57. These organizations are considered to be authorities in the field of radiation protection and measurements, and their recommendations are the basis for radiation protection practice and regulations in countries throughout the world.

Q.13 What accuracy level do these institutions recommend?

A.13 NCRP Report 57 (1978) states:

> The measurement accuracy desirable in personnel dosimetry depends on the radiation level to be measured. At the level of the MPD [Maximum Permissible Dose] a measurement accuracy of $\pm$ 30 percent should be achieved. If the dose equivalent to critical organs is less than 1/4 of the MPD, personnel monitoring is not required and a lower level of accuracy (e.g., a factor of 2) is acceptable.

"Instrumentation and Monitoring Methods for Radiation Protection," NCRP Report 57 (1978) at 63.

ICRU Report 20 (1971) contains the following language concerning accuracy:

> It is suggested that when the MADE [Maximum Dose Equivalent] is comparable to the maximum permissible dose, an accuracy of ± 30% be achieved. When the MADF is considerably less than the MPD, less accuracy is acceptable (e.g., at a level equal to 0.1 of the MPD an uncertainty of as much as a factor of three seems acceptable).

"Radiation Protection Instrumentation and Its Application," ICRP Report 20 (1971) at 7.

ICRP Publication 12 (1968), which was referenced by the NRC Staff ("Affidavit of Seymour Block in Support of Summary Disposition of Joint Contention IV," January 25, 1984, at 2) and by the Board ("Memorandum and Order (Ruling on Motions for Summary Disposition") April 13, 1984, at 11-12) (hereinafter "April 13 Memorandum") for their interpretation of the accuracy requirements, has been superceded officially by ICRP Publication 35 (1982), which states the following concerning the measurement of shallow and deep dose equivalent:

> If these quantities are of the order of the relevant annual limits, the uncertainties should not exceed a factor of 1.5 at the 95% confidence level. Where they amount to less than 10 mSv [1 rem] an uncertainty of a factor of 2 at the 95% confidence level is acceptable.

"General Principles of Monitoring for Radiation Protection of Workers," ICRP Publication 35 at 25. In general, all of these organizations recommend accuracy standards in the range of ± 30 to 50% at dose levels approximating the annual dose limit of 5 rem. At lower dose levels (1 rem), uncertainties on the order of 100% or more are considered acceptable. The standards do not even propose that individual monitoring be required at dose levels less than 25 to 30% of the annual dose limits.

Although the above standards are in general agreement on the subject of accuracy, they are not specific enough to be used as the basis for evaluating the performance of dosimetry systems. For this reason, ANSI N13.11-1983 was established to provide specific criteria for testing the performance of dosimetry processors.

Q.14 What is the ANSI standard?

A.14 ANSI N13.11 (1983) is the current standard used for testing the performance of dosimetry processors under the NBS dosimetry accreditation program, and as such it is the most widely used standard for the accuracy of dosimetry in the nuclear industry.

The ANSI standard sets the tolerance level at 50% for doses from 0.03 to 10 rem and at 30% for doses from 10 to 500 rem. The ANSI performance criterion specifies that for a series of dosimeter measurements the sum of the average absolute bias (P) plus the standard deviation (S) must be less than the specified tolerance level (L). The mathematical expression of the criterion is:

$$P + S < L$$

The average absolute bias is a measure of the deviation of the average measured dose from the true dose, while the standard deviation is a measure of the variation or spread of the individual dosimeter measurements about the average measured dose.

Q.15 Do the TLDs to be used at the Harris Plant satisfy the ANSI standard?

A.15 Yes. The Panasonic TLDs to be used at the Harris Plant were tested in 1982 and 1984 and found to meet the performance specifications of ANSI N13.11-1983. In 1982, testing was conducted at the University of Michigan by Dr. Phil Plato as part of a study sponsored by the NRC. During the study the TLDs were irradiated to a variety of radiation sources whose calibrations were verified by NBS. The methods used during this study are documented in Performance Testing of Personnel Dosimetry Services - Revised Procedures Manual, NUREG/CR-2892 (February 1983), and the results of testing are documented in Performance Testing of Personnel Dosimetry Study - Final Report Test 3, NUREG/CR-2891, page no. 18 (February 1983) (Attachment B hereto). In these reports, CP&L is listed as processor number 187. In 1984, similar testing was conducted to meet the NVLAP accreditation performance test requirements. Again, the testing was conducted at the University of Michigan, which was selected by NBS as the official testing lab for the NVLAP. The results of this testing have been forwarded to NBS and CP&L, but have not been published.

As the table shows, using Panasonic TLD's, CP&L achieved the following performance for categories I through VIII in these two tests:

Category	Radiation Type	1982 CP&L Performance (P+S)	1984 CP&L Performance (P+S)	ANSI Limit
I	X-ray Accident	.24	.18	.3
II	Gamma Accident	.10	.15	.3
III	X-ray Shallow	.11	.18	.5
	X-ray Deep	.12	.16	.5
IV	Gamma	.06	.10	.5
V	Beta	.30	.28	.5
VI	Gamma & X-ray Shallow	.06	.19	.5
	Gamma & X-ray Deep	.16	.18	.5
VII	Gamma & Beta Shallow	.16	.29	.5
	Gamma & Beta Deep	.11	.10	.5
VIII	Gamma & Neutron	*	.09	.5

*CP&L did not participate in this test category in 1982.

The tolerance limit is 0.3 for Categories I and II and 0.5 for all other categories. Thus CP&L passed the tolerance limit for all categories in which it participated during each test. These tests demonstrate that the Panasonic TLDs proposed for the Harris Plant meet the accuracy requirements which have been endorsed by the national consensus standard of ANSI.

Q.16 As the Board noted, in the development of the ANSI standard the criterion was relaxed by changing the passing formula from $P+2S < L$ to $P+S < L$. How would the performance of the TLDs to be used at the Harris Plant compare to the more restrictive criterion?

A.16 First, it should be noted that while the criterion was relaxed from 2S to S, the maximum value for L was tightened from 2.0 to 0.5 for low doses. However, the following table shows CP&L results compared to the criterion of $P+2S < L$. As can be seen, CP&L passed the more restrictive criterion for all categories in which it participated during each test except the accident x-ray category in 1982. In my opinion, it is not realistic to expect that an individual could receive accident level exposures to x-rays in a nuclear power plant.

Category	Radiation Type	1982 CP&L Performance (P+2S)	1984 CP&L Performance (P+2S)	Limit
I	X-ray, Accident	.37	.29	.3
II	Gamma, Accident	.14	.21	.3
III	X-ray Shallow	.16	.26	.5
	X-ray Deep	.22	.25	.5
IV	Gamma	.09	.17	.5
V	Beta	.36	.37	.5
VI	Gamma & X-ray Shallow	.12	.26	.5
	Gamma & X-ray Deep	.23	.28	.5
VII	Gamma & Beta Shallow	.22	.41	.5
	Gamma & Beta Deep	.17	.18	.5
VIII	Gamma & Neutron Deep	*	.15	.5

*CP&L did not participate in this category in 1982.

Q.17 Is the ANSI standard compatible with other nationally recognized standards?

A.17 In general, yes. Only ICRP 35, which defines the acceptable uncertainty in routine monitoring at a specific confidence level can be effectively compared to the ANSI standard. For doses on the order of the annual limit (5 rem), ICRP 35 states that the uncertainties should not exceed 50% at the 95% confidence level. This can be expressed in mathematical terms (in an equation similar to the expression of the ANSI standard) as:

$$P + 2S \leq 0.5$$

For doses below 1 rem, ICRP 35 recommends that the uncertainties not exceed 100% at the 95% confidence level. Mathematically, this is expressed as:

$$P + 2S \leq 1.0$$

The following table shows the relationship between the ANSI and ICRP standards for the simple case where P=0 (i.e. systematic bias is zero):

Dose Range (rem)	ANSI	ICRP
0-1.0	$S < 0.5$	$S \leq 0.5$
1.0-5.0	$S < 0.5$	*
5.0-10.0	$S < 0.5$	$S \leq 0.25$
10-500	$S < 0.3$	$S \leq 0.25$

*ICRP does not clearly address this dose range.

As the table shows, there is relatively good overall agreement between ANSI and ICRP under the simple case when P=0, especially at the dose levels which are most common in practice (doses less than 1 rem).

When P 0, as is usually the case, the comparison of the ANSI and ICRP standards becomes more complex. For the most common dose range (less than one 1 rem), ANSI becomes more restrictive than ICRP. For doses between 5 and 10 rem ICRP is more restrictive. For doses above 10 rem, the standard which is more restrictive depends on the actual values for P and S.

The following examples illustrate that ANSI is more restrictive than ICRP for doses less than 1 rem.

Example 1

Assume P=0.2 and calculate the maximum permissible S according to the ANSI and ICRP formulas.

	Formula	P	Maximum S
ANSI	$P+S < 0.5$	0.2	0.3
ICRP	$P+2S \leq 1.0$	0.2	0.4

As can be seen ICRP allows a larger S for a given P.

Example 2

Assume S=0.2 and calculate the maximum permissible value for P according to ANSI and ICRP formulas:

	Formula	S	Maximum P
ANSI	$P+S < 0.5$	0.2	0.3
ICRP	$P+2S \leq 1.0$	0.2	0.6

Again, ICRP allows a larger P for a given S.

Thus, overall, the ANSI standard and ICRP recommendations are relatively compatible, especially at the dose levels which are most common in practice (doses less than one rem).

Q.18 Is CP&L committed to maintaining the ANSI standard at the Harris Plant?

A.18 Yes. A quarterly TLD intercomparison program has been established with the University of Michigan. This program follows the format of the ANSI performance test, except that CP&L has added two additional radiation categories which are applicable to the radiation types and energies found in its nuclear plants, and has dropped the accident categories which differ from other categories only in the dose level. This provides a regular, independent test of the TLD system against the ANSI criterion.

Q.19 Which two categories have been added by CP&L?

A.19 CP&L has added new categories for low energy beta and for mixtures of low energy beta with high energy photons. These two categories are designed to test more fully the TLD system capability under exposure conditions which are similar to those which can occur under certain working conditions in the CP&L plants.

Q.20 What results have been obtained in those categories?

A.20 The results for these two categories in tests conducted during the first quarter of 1984 are shown below:

Radiation Type		CP&L Performance (P+S)	Limit
Beta (low)	shallow	.40	.5
Gamma (high) & Beta (low)	shallow	.26	.5
Gamma & Beta	deep	.22	.5

It should be noted that this test represented the first actual exposure of CP&L TLDs to these categories. The calibration factor used during these tests was based on the best available information in the literature prior to the test, rather than on experimental data specific to the CP&L system. Based on these test results and additional beta dosimetry studies performed by CP&L in conjunction with the University of Lowell during 1984, adjustments have been made so that future performance can be expected to improve significantly.

Q.21 Are there any existing regulatory requirements that specify TLD accuracy?

A.21 No. I understand that the Board views 10 C.F.R. Part 20 as establishing implicit limits for TLD accuracy. In my opinion, Part 20 sets limits on the maximum <u>recorded</u> quarterly and yearly dose to various parts of the body, but does not specifically set forth an accuracy standard for measurement of dose.

Q.22 What accuracy standard has been suggested by the Board?

A.22 With regard to the NRC regulatory standards for radiation dose to individuals, the Board initially noted:

> There is no indication of any latitude or permissible variance in the application of these standards that would give the Board guidance concerning the accuracy required in dosimetric procedures.

From this statement, I believe that the Board is in basic agreement with my earlier statement that the regulations contain no explicit standard for accuracy. However, the Board derived an implied standard of accuracy from 10 C.F.R. § 20.407(b), which provides for a statistical summary report of recorded doses. The Board's interpretation was stated as follows:

> The Board derives from these regulations an implication that the required radiation exposure control is in terms of integer values in rem units.

April 13 Memorandum at 9.

The Board has clarified this language, based on the NRC Staff's guidance:

> The Board accepts the Staff's guidance as cited, and we note that the specification of the limit on the uncertainties as 50 percent is compatible with our reading of the regulations as specifying integer values at occupational exposure levels.

Id. at 12. The Board also stated:

> As noted above, the Board accepts the Staff's guidance in terms of the ICRP recommendation that at a dose level of 2 rem, 1 rem uncertainty is acceptable.

Id. at 16.

By these statements, the Board appears to suggest 50% as an accuracy standard without reference to a specific confidence level.

After suggesting 50% as the standard, the Board expressed its interpretation of the confidence level requirement as follows:

> The essential issue from the Board's point of view is that reasonable worker radiation protection and demonstrations of regulatory compliance are not compatible with the acceptance of performance with a standard deviation of 0.5. Conventional interpretation of the 0.5 standard deviation would be that at the 95 percent confidence level an individual dose estimate would be uncertain by ± 100 percent. This range or latitude is not compatible with the Board's reading of the regulations as calling for controlling radiation doses to workers with a resolution to integer values at 1 rem and above.

Id. at 16. I must note, however, that this statement overlooks the fact that, according to the ANSI criterion, the sum of the bias plus the standard deviation -- not just the standard deviation -- must be within 0.5. But in any case, the Board appears to consider the 95% confidence level to be appropriate. Combined with previous statements, the standard which the Board seems to have suggested is 50% at the 95% confidence level.

The Board also suggested an alternative interpretation for the accuracy standard as follows:

> As the Board has outlined above, we believe that NRC regulations require that personal dosimetry be carried out in a manner such that the results can be relied upon to be accurate to integer values or one significant figure for doses of a few rem. Such performance could be achieved by limiting acceptable bias to 10 to 20 percent and variability or the standard deviation also to 10 to 20 percent.

Id. at 19. This proposal is different from the Board's other suggestions in the April 13 Memorandum since no confidence level is specified and ranges, rather than single values, are provided for bias and variability. It could be interpreted as allowing a bias of 20% and standard deviation of 20% at the 95% confidence level, thus yielding a total uncertainty of 60% rather than 50% as espoused earlier.

In its ruling on the CP&L motion to reconsider its order on summary disposition, the Board suggested what appears to be a third interpretation of the accuracy standard:

> The issue that we are leaving in [the licensing proceeding] reflects our view that the existing regulations do embody a standard of accuracy. They require that the Applicants' dosimetry program reliably distinguish between doses of 2 and 3 rems and between 3 and 4 rems; that is to say, errors of larger than half a rem are not permitted.

Tr. 2218-19, August 10, 1984 Conference Call.

I am unable to reconcile this statement with the Board's previous statements to the effect that an accuracy level of 50% may be required. The standard suggested at the time of the conference call would result in a different accuracy level for each dose level. Only at a dose of 1 rem would an error of 0.5 rem represent 50% uncertainty.

Q.23 What conclusions have you drawn regarding the Board's suggestion of an implied standard for TLD accuracy?

A.23 I have carefully analyzed the Board's statements regarding accuracy and reached the following conclusions:

First, as acknowledged by the Board, NRC regulations do not presently contain any explicit guidance on the accuracy required in dose measurements. As noted by the Board in its ruling on Applicants' motion for reconsideration, the NRC's rulemaking proceeding will resolve the question of the accuracy for Applicants and all other licensees. Tr. 2217-18, August 10, 1984 Conference Call.

Second, the Board has not articulated a single, unambiguous technical standard for accuracy against which CP&L TLD performance could be measured.

Third, the various statements made about accuracy by the Board are not entirely consistent with the guidance of the prevailing standards established by ANSI and ICRP. Applicants are committed, however, to maintaining, at a minimum, the ANSI standard.

Q.24 Would you consider a requirement of accuracy within 50% at the 95% confidence level for doses of a few rem to be an appropriate standard for TLD accuracy?

A.24 No. This standard was suggested by the Board, relying, in part, on ICRP 12 (1968). However, as I have noted, ICRP 12 has been superceded by ICRP 35 (1982) which provides more recent and specific guidance on the subject of accuracy in routine monitoring. For doses on the order of the annual limit (5 rem) ICRP 35 states that the uncertainties should not exceed 50% at the 95% confidence level. Therefore the standard suggested by the Board is essentially consistent with the recommendations of ICRP 35 for doses on the order of 5 rem or greater. However, 5 rem is the annual exposure limit and the actual annual exposure of most workers is below this level. In fact, less than 10% of the workers monitored at the H.B. Robinson Plant (CP&L's operating pressurized water reactor ("PWR")) received annual doses during 1983 greater than 1 rem. The Robinson Plant is a single-unit, Westinghouse-designed PWR similar to the Harris Plant. At dose levels below 1 rem, ICRP 35 recommends that the uncertainties not exceed a factor of 2 (100%) at the 95% confidence level. This recommendation is essentially equivalent to the ANSI criterion of P+S 0.5, as I previously explained in response to question 17. Although the Board's interpretation that accuracy should be within 50% for doses of a few rem is appropriate for doses of 5 rem or greater, in my opinion it is not appropriate or consistent with ICRP or ANSI recommendations for doses of 1 rem or less, which constitute the majority of actual exposures received.

Q.25 Do the TLDs to be used at the Harris Plant nonetheless comply with an accuracy requirement of 50% at the 95% confidence level as suggested by the Board?

A.25 Yes. As previously shown, P+2S was less than 0.5 for all categories during the 1982 and 1984 tests.

Q.26 The Board also suggested that acceptable performance could be achieved by limiting bias and variability to 10 to 20%. Do the TLDs to be issued at the Harris Plant meet this criterion?

A.26 Yes. During the 1984 ANSI tests, no individual category had either bias or standard deviation greater than 20%. During the 1982 ANSI tests, no individual category had a standard deviation greater than 20%, and only one category had a bias greater than 20% (beta--24%). During both the 1982 and 1984 tests, the average bias and standard deviation for all categories was less than 10%. A table setting forth the bias and standard deviation as separate values has been prepared and is attached to this testimony as Attachment C. As the table shows, the results achieved by CP&L more than meet the Board's performance criteria.

Q.27 Would you consider a standard of accuracy within 1/2 rem as suggested by the Board to be an appropriate standard for TLD accuracy?

A.27 No. A standard worded in this way represents a different level of accuracy on a percentage basis at every dose level. The following table shows how the percent error allowed would vary as a function of dose. At both high and low doses, the allowed error is unreasonable. A standard is incomplete if it does not cover both high and low doses. Thus, the definition of accuracy stated above is not useful in practice.

Dose	Absolute Error	Percent Error Allowed
0.1	0.5	500%
0.5	0.5	100%
1.0	0.5	50%
2.0	0.5	25%
5.0	0.5	10%
10.0	0.5	5%

Q.28 What steps will CP&L take to ensure that the TLD system at the Harris Plant continues to meet the applicable standard for accuracy?

A.28 As stated in NUREG-2891, four common reasons for poor performance of dosimetry processors were observed during the 1982 tests at the University of Michigan. These causes of inaccuracy were: 1) use of incorrect calibration factors; 2) dosimeter variability; 3) clerical errors; and 4) poor calibration for accident doses. CP&L has taken steps to minimize errors in each of those four areas.

Q.29 How does CP&L seek to minimize the use of incorrect calibration factors?

A.29 Extensive quality control measures are applied to the processing of TLDs and recording of individual doses to ensure accuracy. With regard to incorrect calibration factors, CP&L has taken the following approach. First, calibration factors have been determined for the TLD system based on irradiation of TLDs to NBS traceable radiation standards for beta, gamma, x-rays, and neutrons. Second, these correction factors have been verified by the tests performed at the University of Michigan in 1982 and 1984, which were discussed previously, and by the on-going quarterly intercomparison program previously mentioned. If calibration factors were not valid, the performance on these tests would so indicate. Third, a monthly in-house cross-check program is in operation. Under this program, blind audit TLDs irradiated with an NBS traceable dose standard are processed on each TLD reader. The performance limit (P+S) of 0.3 is more restrictive than the ANSI limit of 0.5. Fourth, each TLD reader is calibrated semiannually and following any maintenance which affects calibration. A preventative maintenance program is followed for all equipment. Fifth, a daily calibration check using TLDs irradiated to known doses using NBS traceable standards is performed. The performance limit for this check requires the accuracy to be within 15%. Sixth, numerous critical parameters in the TLD reader are monitored automatically prior to reading each TLD badge to ensure stability of equipment during operation.

Q.30 How accurate is CP&L's semi-annual calibration equipment?

A.30 The acceptance criterion for semi-annual calibration of TLD readers requires that 10 TLDs be read at each of 5 known dose levels ranging from 0.25 to 4.0 rem. At each dose level, the average observed reading must be within ± 10% of the actual irradiated dose and the percent standard deviation must not exceed 10%.

Q.31 What about the daily calibration check of TLD reading equipment?

A.31 For daily TLD reader calibration checks, TLDs are read after being irradiated to the following known doses: 0.5 rem and 4.0 rem. Each TLD must read within ± 15% of the actual irradiated dose. If a reading within ± 15% is not obtained, the check is repeated two more times; if the check fails two out of three times, the TLD reader is removed from service. If the observed dose is outside ± 25% of the actual dose, all TLD readings since the last satisfactory check are reviewed to determine whether they are valid.

Q.32 What steps are taken to minimize dosimeter variability?

A.32 CP&L performs an initial acceptance test on each TLD prior to placing it in service. This test identifies TLDs whose response to known radiation doses falls outside approximately the 99% probability level relative to the mean of a sample of at least 500 TLDs. For samples containing less than 500

TLDs, the acceptance criterion requires the TLD response to be within ± 15% of the irradiated value. TLDs which fail initial acceptance testing are returned to the manufacturer for replacement. After being placed in service, all TLDs undergo semiannual quality control checks to detect any change in response. The same procedures and acceptance criteria are used during these quality control checks, and any TLDs which fail are removed from service.

Q.33 Are steps taken to prevent clerical errors?

A.33 With regard to clerical errors, CP&L has implemented automatic data processing techniques and detailed verification procedures. Individual dose records are maintained using a computer system. The TLD readers are interfaced to this computer system, and most TLD readings are transferred electronically to the assigned individual's dose history record. Of course, no data is transferred to the computer system prior to a technical review of the data, and built-in checks ensure the data is tranferred completely and correctly. Through electronic transfer and automated data processing techniques, the opportunity for clerical errors is greatly reduced.

Although some data is still entered into the computer system manually, all manual data entry is independently verified by a different individual. In many cases, the data entry is actually verified twice by two different individuals. In addition, hard copies of all source documents are retained permanently on microfilm to backup the computer record system.

Q.34 What steps has CP&L taken with regard to poor calibration for accident doses?

A.34 With regard to poor calibration for accident doses, CP&L has performed in-house tests which establish the dose response of the TLDs up to doses of 100 rem. The response is essentially linear within approximately ± 15%. In addition, CP&L has participated in and passed the accident dose categories during ANSI performance tests in 1982 and 1984. The ANSI accident test range is 10 rem to 500 rem. This verifies that poor calibration for accident doses is not a problem at CP&L.

Q.35 Has CP&L undertaken other measures to minimize the potential for poor TLD performance?

A.35 In addition to the specific quality control measures described above which address the major reasons for poor performance noted in NUREG CR-2891, the overall quality assurance program includes: (1) detailed written procedures for the performance of all routine dosimetry operations; (2) formal training and qualification for all operating personnel; and (3) formal supervisory review of all quality control records. All of these measures ensure that TLDs will be used and processed correctly at the Harris Plant.

In addition, as part of the overall quality control effort, CP&L has applied for accreditation of its dosimetry laboratory under the recently announced Dosimetry Processor Laboratory Accreditation Program administered by the NBS. CP&L has successfully completed the performance testing requirements for acc.editation. The on-site inspection of CP&L by NVLAP assessors was completed in late August.

Furthermore, while CP&L is confident that its dosimetry program is in compliance with NRC regulations, additional improvements are always being made in an effort to maintain a state-of-art program. Recently, major studies have been completed in the areas of beta and neutron dosimetry. These studies were designed to characterize the response of the TLDs to the typical radiation spectra found in CP&L's nuclear plants and to use this knowledge to improve the accuracy of measurement of personnel doses. CP&L continually seeks to upgrade the quality of its dosimetry program through the better training of personnel, new equipment, and improved procedures.

Q.36 Please summarize your opinion of the adequacy of CP&L's TLD system for use at the Harris Plant.

A.36 In my opinion, CP&L has a well-established, state-of-the-art dosimetry program which has operated successfully for over ten years. The program employs up-to-date equipment and facilities. Within the last three years CP&L has invested well over one million dollars in TLD equipment and has committed over $200,000 more this year for additional equipment to support the Harris Plant. A highly trained and experienced staff is maintained to provide dedicated support to the dosimetry program. The central support staff includes four professional personnel, five technicians, and two clerks. Each operating plant, including the Harris Plant, also maintains or will maintain a separate dosimetry staff headed by a dosimetry foreman. The program is operated under detailed quality assurance procedures which incorporate elaborate quality control checks on all aspects of dosimetry processing and record keeping.

CP&L's use of TLDs satisfies all applicable NRC regulations, is in substantial compliance with the standards of the nationally and internationally recognized organizations in the field, and conforms to the ANSI N13.11 standard that is the basis for the NVLAP program and the proposed NRC rule. Thus, the dosimetry program to be established at the Harris Plant, utilizing Panasonic TLDs and CP&L's calibration and quality control program, has already demonstrated a consistent degree of accuracy in radiation doses measurement to ensure compliance with NRC regulations and is adequate to protect worker health and safety.

ATTACHMENT A

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Harris Energy & Environmental Center
Carolina Power & Light Company
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Education and Training

B.S. degree in Physics, Union College (1971)

M.S. degree in Environmental Health Engineering, Northwestern University (1974)

Professional Societies

Health Physics Society

Experience

A. 1972 to 1974 - Radiation Safety Officer, Packard Instrument Company, Downers Grove, Ill.

B. 1974 to September 1978 - Health Physicist, General Electric Company, Knolls Atomic Power Laboratory, Windsor, Conn.

September 1978 to April 1979 - Lead Engineer, General Electric Company, Knolls Atomic Power Laboratory, Windsor, Conn.

C. April 1979 to October 1981 - Senior Specialist - Dosimetry, Carolina Power & Light Company, New Hill, N.C.

October 1981 to present - Project Specialist - Health Physics, Carolina Power & Light Company, New Hill, N.C.

ATTACHMENT B

NUREG/CR-2891

Performance Testing of Personnel Dosimetry Services

Final Report of Test #3

Manuscript Completed: November 1982
Date Published: February 1983

Prepared by
P. Plato, J. Miklos

The University of Michigan
School of Public Health
Ann Arbor, MI 48109

Prepared for
Division of Facility Operations
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B1049

Table 3 continued.

Radiation Categories	I X ray Accident	II Gamma Accident	III X ray Shallow	III X ray Deep	IV Gamma	V Beta	VI Gamma + X ray Shallow	VI Gamma + X ray Deep	VII Gamma + Beta Shallow	VII Gamma + Beta Deep	VIII Gamma + Neutron
Dosimeter Code Number											
182			0.5024	0.1335	0.1005	0.5300	0,3693	0,0891	0.1902	0.0526	1.7145
183					0.0627	0.8957			0,8006	0,0931	
184					0.5416						1.2909
185	0.1297	0.0919	0.1631	0.1881	0.1196	0.0831	0.1723	0,2052	0.1710	0,0843	0,1908
186*											
187	0.2406	0.1052	0.1041	0.1228	0.0614	0.3053	0.0583	0.1594	0.1640	0.1060	
188	0.9237	0.6027	1.0567	0.6499	0.2434	0.3791	0.8830	0.6737	0.5767	0.3368	0.9632
189	0.2355	0.1608	0.3993	0.6199	0.2607	0.3423	0.3385	0.2740	0.4060	0.3176	0.2812
190			0.5470	0.5344	0.1708	0.5538	0.3569	0.3696	0.4432	0.3985	0,1453
191*											
192	0.3187	0.1155	1.4558	0.5534	0.2076	1.4166	0.6948	0.3518	0.7508	0.4031	0.6550
193	1.9733	0.7837	3.0410	0.0966	0.0499	0.1220	3.3129	0.1167	0.1235	0.1860	0.3201
194	1.0326	0.5363	1.4322	1.0703	0.0652	0.2885	1.6137	0.3667	0.1670	0.0818	0.1844
195*											
196					0.2982	0.2348			0.3628	0.4340	
197	0.3867	0.1307	0.4789	0.4493	0.1022	0.1111	0.3294	0.2351	0.1173	0.1225	0.0939
198*											

ATTACHMENT C

CAROLINA POWER & LIGHT

ANSI-N13.11-1983 PERFORMANCE TESTING COMPARISON

			2nd Qtr 1982			1st Qtr 1984			
CATEGORY	DESCRIPTION	DEPTH	P	S	P +S	P	S	P +S	L
I	Accident, Low-Energy Photon	Deep	.11	.13	.24	.07	.11	.18	.3
II	Accident, High-Energy Photon	Deep	-.06	.04	.10	-.09	.06	.15	.3
III	Low Energy Photons	Shallow	.06	.05	.11	.10	.08	.18	.5
		Deep	.02	.10	.12	.07	.09	.16	.5
IV	High Energy Photons	Deep	-.03	.03	.06	-.03	.07	.10	.5
V	Beta Particles	Shallow	.24	.06	.30	.19	.09	.28	.5
VI	Photon Mixtures	Shallow	.00	.06	.06	.12	.07	.19	.5
		Deep	.09	.07	.16	.08	.10	.18	.5
VII	Photon plus Beta	Shallow	.10	.06	.16	.17	.12	.29	.5
		Deep	.05	.06	.11	-.02	.08	.10	.5
VIII	Photon plus Neutrons	Deep	-	-	-	.01	.07	.09	.5
	Average		.08	.07	.13	.06	.09	.17	

P = Performance quotient = (Reported-Delivered)/Delivered

S = Standard deviation of P

L = Tolerance limit

Applicants' Exhibit __
Joint Contention IV
Docket No. 50-400 OL

Specifications of TL Badge and
TL Badge Hanger
(Thermoluminescent Dosimeters)

SPECIFICATION OF
TL BADGE
MODEL SPECIFICATIONS

UD-801A
UD-802A
UD-803A
UD-804A
UD-806A
UD-807A
UD-808A
UD-809A
UD-811A
UD-815A

MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
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OSAKA, 561 JAPAN

* Specifications subject to change without notice.

MODEL SPECIFICATIONS

TL Badge : UD-802A group

Refer to the GENERAL SPECIFICATIONS for common specifications.

1. Model number : UD-802AQ , UD-802AR , UD-802AS
2. Use : Personnel monitoring
3. Applicable reader : UD-710A, UD-702E, UD-720A
4. Appearance : Fig. 1
5. Element and shield composition : Table 1
6. Measurable rays and range : γ·x rays (10keV ∿ 10MeV) 1mrem ∿ 1000rem (Rough energy evaluation is possible)
   β rays (0.5MeV ∿ 4MeV) 10mrem ∿ 1000rem

   (Measurable range is in the case where single kind of rays is measured.)
7. Recommended hanger : UD-875A, UD-885A
8. ID number : Specified serial numbers (7digits at maximum) are punched.
9. Label : The labels shown in Fig. 1 are sticked.
10. Weight : Less than grams.

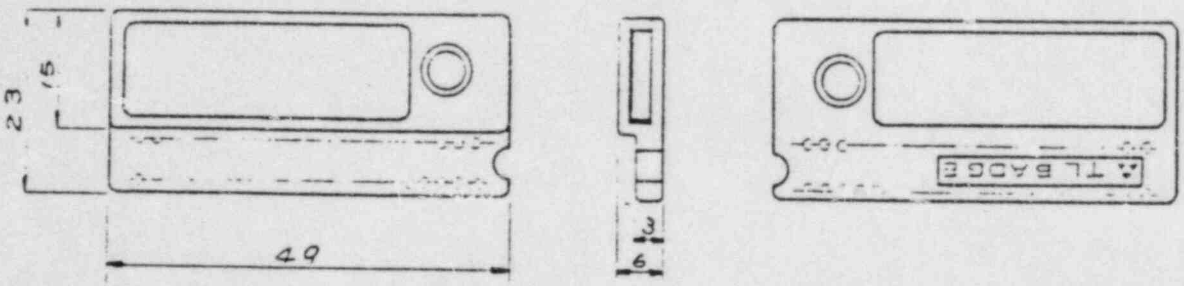

Fig. 1 Appearance of TL Badge: UD-802AQ
(The figure also applies to UD-802AR and UD-802AS)

Table 1 Element and shield composition of TL Badge UD-802A group

Element	Phosphor	Shield
E1	$^{n}Li_2{}^{n}B_4O_7$(Cu)	Plastics 14mg/cm^2
E2	$^{n}Li_2{}^{n}B_4O_7$(Cu)	Plastics 160mg/cm^2
E3	$CaSO_4$(Tm)	Plastics 160mg/cm^2
E4	$CaSO_4$(Tm)	Lead 0.7mm thick

* The thickness of the hanger is not included. To obtain the total thickness when the badge is placed in the hanger, refer to the specifications of the hanger and add that thickness for each element.

SPEC NO. E-BDG/GS-1

SPECIFICATION OF
TL BADGE

GENERAL SPECIFICATIONS

JANUARY 1983

MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
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CONTENTS

INTRODUCTION

These specifications are common to all National/Panasonic TL Badges. As for detailed specifications, such as phosphorous materials and shield combinations, refer to the "Specifications for each TL Badge model."

For many measurements and dosage assessment applications, the National/Panasonic TL Badge must be used with a TL Badge Hanger.

As for the National/Panasonic TL Badge Hanger, refer to the "Specifications common to all TL Badge Hangers" and the "Specifications for each TL Badge Hanger model."

1. GENERAL

The TL Badge is a thermoluminescence dosimeter for measurement of integral dose of radation.

Elements (up to four) are mounted on an element plate. The element plate is put in the badge holder. The element is made of a thin layer of thermoluminescence phosphor. A radiation shield is provided on the badge holder.

An identification number (up to seven digits) is provided on the badge and automatically read by a reader.

The badge is measured without the necessity of taking the element plate out from the badge holder. The element plate is locked to the badge holder to prevent deliberate removal of the plate.

2. APPEARANCE AND CONSTRUCTION

Figure 1 (a), (b), (c) shows the appearance of the TL Badge. Depending on the use, three types are available; one-window type, two-window type, and no-window type. An extremity dosimeter shown in figure 1 (d) is also available. Forty-bit optical code holes can be made in the badge holder to provide the ID number, etc.

Figure 2 shows the sectional view and the dimensions of the TL Badge. (Though it shows the one-window type UD-802A, the figure also applies to other types.)

Figure 3 shows the enlarged sectional view of the element.

Virtually mono-layer of granular phosphor (average granule diameter is 90μ) is formed on the thin resin substrate. The phosphor is covered with a protective, transparent film.

3. DETAILED COMMON SPECIFICATIONS

3-1 Thermoluminescence phosphor

Depending on specific measurement, four kinds of phosphor are mounted on the plate in various combinations.

$^{n}Li_2{}^{n}B_4O_7(Cu)$ The phosphor is made of tissue-equivalent $Li_2B_4O_7$ with Cu doped as an activator. Natural abundant material ^{n}Li and ^{n}B is used for Li and B. The phosphor is sensitive to γ.x rays and β rays and somewhat sensitive to low-energy neutron.

$^{7}Li_2{}^{11}B_4O_7(Cu)$ ^{n}Li and ^{n}B in $^{n}Li_2{}^{n}B_4O_7(Cu)$ mentioned above are replaced by enriched material ^{7}Li and ^{11}B. The phosphor has little sensitivity to neutron rays. The response to γ.x rays and β rays is equivalent to $^{n}Li_2{}^{n}B_4O_7(Cu)$

$^{6}Li_2{}^{10}B_4O_7(Cu)$	^{n}Li and ^{n}B in $^{n}Li_2{}^{n}B_4O_7(Cu)$ mentioned above are replaced by enriched material ^{6}Li and ^{10}B. The phosphor has high sensitivity to low-energy neutron rays. The response to γ.x rays and β rays is equivalent to $^{n}Li_2{}^{n}B_4O_7(Cu)$.
$CaSO_4(Tm)$	The phosphor is made of non-tissue-equivalent $CaSO_4$ with Tm doped as an activator. Since the phosphor has high sensitivity it is used to evaluate low dose in combination with metal shield. Without metal shield, it shows over response to low-energy γ.x rays, and is used for energy evaluation of γ.x rays. The phosphor has little sensitivity to neutron rays.

3-2 Element Thickness

a) Phosphor layer: Approx. 15 mg/cm^2

b) Substrate: Approx. 11 mg/cm^2

c) Transparent cover film: Less than 28mg/cm^2

3-3 Measurement Range

a) $Li_2B_4O_7(Cu)$ elements: 10 mrem to 1000 rem (^{60}Co-γ ray equivalent)

b) $CaSO_4(Tm)$ element: 1 mrem to 200 rem (^{60}Co-γ ray equivalent)

3-4 Fading

a) $Li_2B_4O_7(Cu)$ elements: Less than 10%/month,

b) $CaSO_4(Tm)$ element: 3%/month,

at the room temperature (25°C)

3-5 Tribo-thermoluminescence

a) $Li_2B_4O_7(Cu)$ elements: Lower than detection limit,

b) $CaSO_4(Tm)$ element: Lower than detection limit.

3-6 Light Response (light sensitivity and light fading)

a) $Li_2B_4O_7(Cu)$ elements: Lower than detection limit,

b) $CaSO_4(Tm)$ element: Lower than detection limit,

where mounted in the badge holder.

3-7 Sensitivity uniformity of element

There are three classes in the nominal uniformity of element; Class Q, Class R, and Class S. The class is indicated in the seventh digit of the model number. (Example: UD-802AQ, UD-802AR, UD-802AS etc.)

Nominal uniformity indicated by the classes are as follows:

Class	Nominal uniformity		
Q	Percentage standard deviation	$\leqq$	5.0%
R	Percentage standard deviation	$\leqq$	7.5%
S	Maximum to minimum deviation	$\leqq$	±30%

It is assumed that the uniformity is evaluated using the reader with rank correction function.

In evaluating uniformity, Class Q sometimes shows a percentage standard deviation of 5 to 6% and Class R does 7 to 8% depending on the exposuring method and sampling method.

3-8 Life Time

Repeated use: 300 times,

Total exposure: Lower than 10 rem (^{60}Co-γ ray equivalent)

3-9 Working Conditions

Temperature: -10°C ∿ 40°C (Fading increases above 35°C.)

Humidity: Less than 80% RH (without dripping)

For precautions before measurements, refer to the handling instructions.

3-10 Bit Format of Optical Code Hole on the TL Badge

The bit format of the optical code hole is shown in Fig. 4.

The 40 bits are used as follows;

28 bits : Number code (7 digits)

4 bits : Model code

6 bits : Element sensitivity correction code

2 bits : Parity code (Odd parity)

4. GUARANTEE

<u>One year from date of delivery.</u>

Replacement of new badge shall constitute a fulfillment of all obligations to the purchaser. The Panasonic will not be responsible for any damage resulting from improper use.

Please read the handling instructions carefully before use.

Appendix 1.

Model number format

The model number of TL Badges is constituted as follows;

```
U D - 8 [1  2] A [0][3]
\_______/ \____/ \_/ \_/ \_/
    ^      (i)   ^ (ii)(iii)
    |            |
  Common       Common
  term         term
```

(i) . A code defining the composition of the element and shield.

[0|1] to [1|5]

. Codes from [0|1] to [1|1] are assigned to standard specification badges and the composition is fixed.

. Codes from [1|2] to [1|4] are assigned to special specification badges and the composition is determined by the purchaser. (Refer to (iii).)

(In this case, the reader parameter must be set according to the badge composition. The badge defining parameter for the UD-702E manual operation reader cannot be varied.)

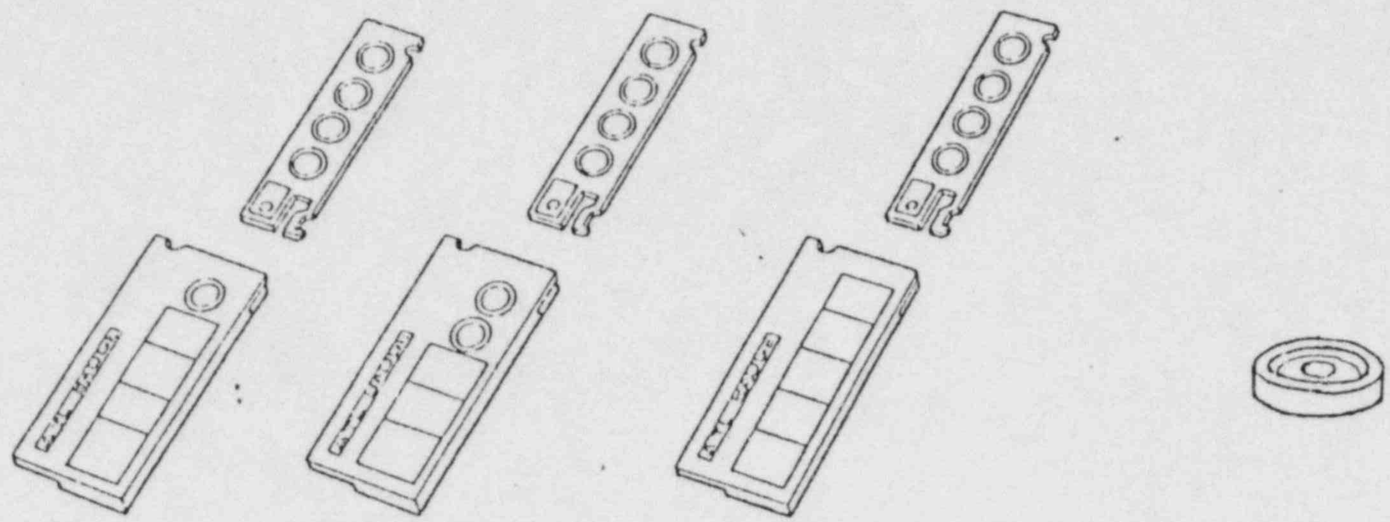
. Code [1|5] is assigned to the reader calibration badge.

(ii) A code defining the nominal uniformity class. (Refer to 3-(7).)

(iii) Special code

When a special specification code (between [12] and [14]) is assigned to term (i), many TL Badges containing the same model number will result. To identify these badges, a serial number is assigned to the badges. For example, UD-812AQ has many variations: UD-812AQ1, UD-812AQ2, ... and incorrect readings will result when UD-812AQ1 is read by the reader given the badge defining parameters for UD-812AQ2.

(The special code may be assigned to the standard badges when necesary.)



(a) one-window type (b) two-window type (c) no-window type (d) extremity dosimeter

Fig. 1 Appearance of TL Badge

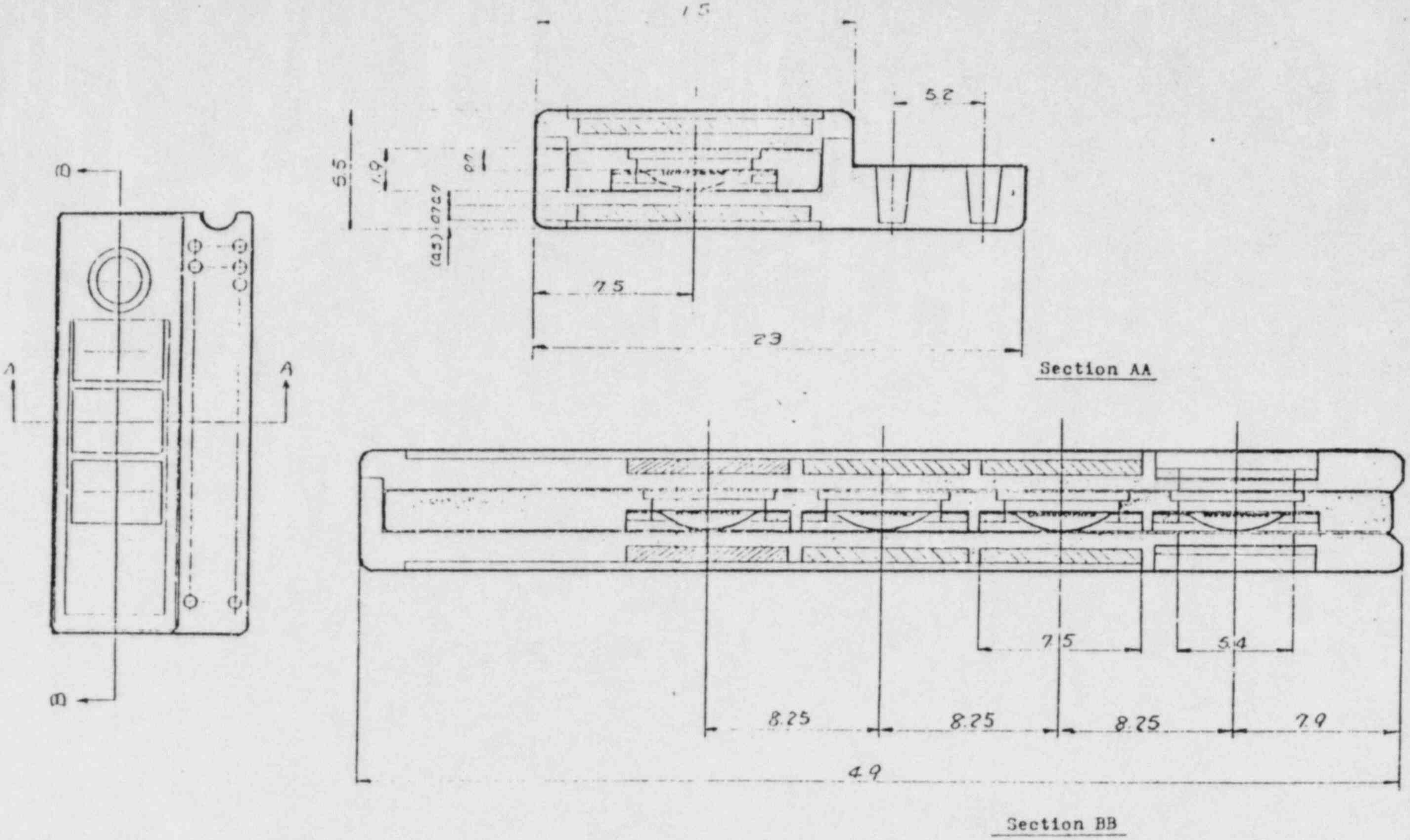


Fig. 2 Sectional view of the TL Badge

(UD-802A as an example).

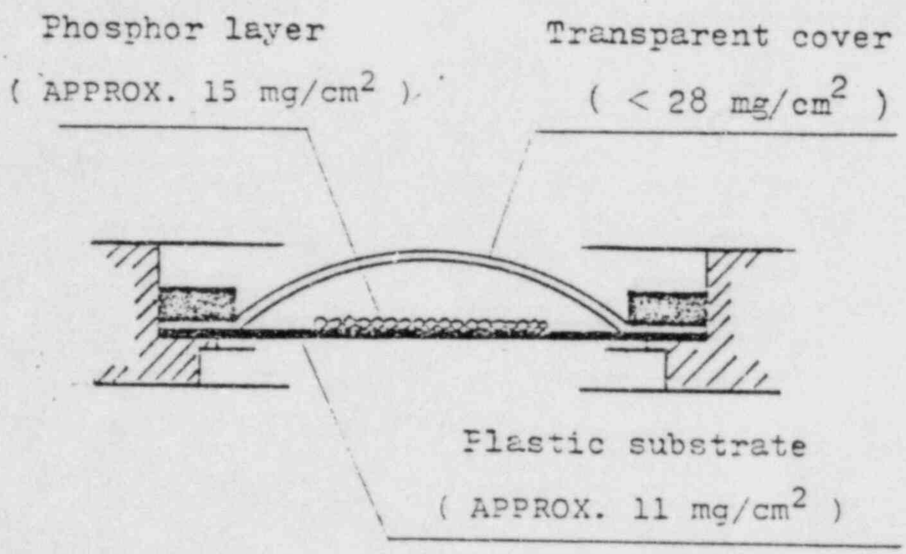


Fig. 3 Enlarged sectional view of the element.

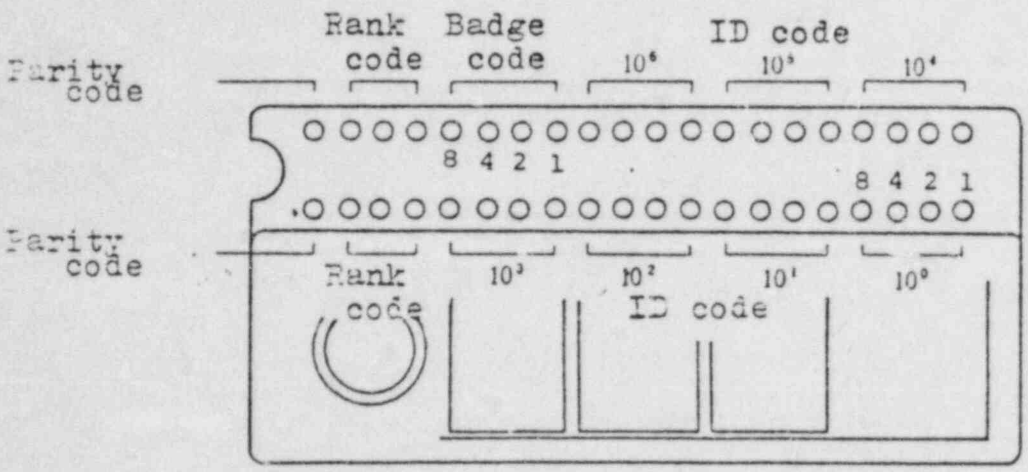


Fig. 4 Bit format of optical code hole.

SPECIFICATION OF

TL BADGE HANGER

MODEL SPECIFICATIONS

UD-854A
UD-874A
UD-875A
UD-876A
UD-885A
UD-886A
UD-887A

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* Specifications subject to change without notice.

MODEL SPECIFICATIONS

TL Badge Hanger : UD-854A(H)

Refer to the GENERAL SPECIFICATIONS for common specifications.

1. Model number	:	UD-854A UD-854AH
2. Type	:	Open type for one badge
3. Applicable TL Badge (Examples)	:	UD-801A, UD-815A
4. Appearance	:	Fig. 1
5. Body material	:	ABS resin
6. Front wall thickness	:	For element 1 open for element 2 plastics 160 mg/cm^2 for element 3 plastics 160 mg/cm^2 for element 4 plastics 160 mg/cm^2
7. Attaching device	:	An alminium clip (with a nylon strap : UD-854AH only)
8. Color	:	[illegible] h slight smokiness.
9. Weight	:	Less than grams.

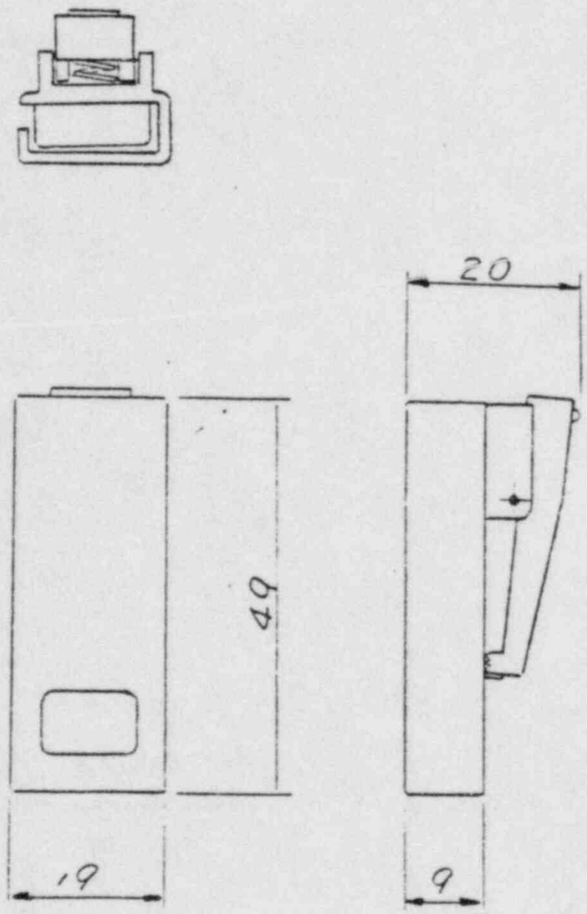

Fig. 1 Structure of hanger: UD-854A.

S.A. BROWNE

SPEC NO. E-HGR/GS-1

SPECIFICATION OF
TL BADGE HANGER
GENERAL SPECIFICATIONS

JANUARY 1983

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* Specifications subject to change without notice.

CONTENTS

INTRODUCTION

These specifications are common to all National/Panasonic TL Badge Hangers. As for detailed specifications regarding each hanger, refer to the "Specifications for each TL Badge Hanger model."

For many measurements and dosage assessment applications, the National/Panasonic TL Badge must be used with the TL Badge Hanger.

As for the National/Panasonic TL Badge, refer to the "Specifications common to all TL Badges" and "Specifications for each TL Badge model."

1. General

The TL Badge Hanger serves as both a wearing case and as an additive shield for the TL Badge. Except for special cases, TL Badges should be placed in the hanger before being used.

There are three kinds of hangers: an open hanger for single badges, a closed hanger for single budges, and a closed hanger for two badges.

2. Construction

The three above hangers are shown in Fig. 1.

A γ-ß TL Badge is encased in an open hanger, a closed hanger, and also in the right side of the closed hanger for two badges. The hangers are available in several thickness depending on the γ-ß TL Badges used. The UD-809A neutron TL Badge is placed in the left side of the closed two-badge hanger.

The open hanger has a window for the ß badge. The closed hanger's window is sealed with a 3 mg/cm^2 thick plastic film, making its wall thickness slightly larger for the ß-rays (skin dose) estimating element. The projection shown in Fig. 1 (b) and (c) provides a wall thickness of 1000 mg/cm^2 for the deep dose estimating element.

Closed hangers are designed so that they cannot be easily opened without special jigs. There is a space for a label on each surface.

3. Shielding

3-1 Shielding for γ-β TL Badges

The front wall of the hanger is made of plastic. The thickness of each model is specified in the specifications for each model.

When a TL Badge is encased in a hanger, the total thickness for the γ.x and β rays is obtained by adding the hanger thickness to the badge shield thickness. Examples are shown in Appendix 1.

3-2 The shield for a neutron badge

An additional cadmium-made shield for the UD-809A neutron badge can be formed on the left side of the closed two-badge hanger.

4. Guarantee

This guarantee is good for three months from the date of delivery. This guarantee does not cover problems caused by misuse, abuse, or negligence.

Panasonic will repair or replace, at no charge, your TL Badge Hanger if any problem develops during the guarantee period due to design or workmanship defects.

(Refer to "TL Badge Handling Instructions" for handling.)

Appendix 1. An example of calculation of total wall thickness

Example : UD-808A TL Badge in UD-887A Hanger

Element	Phosphor	Shield thickness of UD-808A	Wall thickness of UD-887A	Total thickness	Remarks
E1	$^7Li_2{}^{11}B_4O_7(Cu)$	Plastics 14 mg/cm^2	Plastics 3 mg/cm^2	Plastics 17 mg/cm^2	For ß-ray (skin dose) evaluation including ß-ray energy correction.
E2	$^7Li_2{}^{11}B_4O_7(Cu)$	Plastics 60 mg/cm^2	Plastics 3 mg/cm^2	Plastics 63 mg/cm^2	
E3	$CaSO_4(Tm)$	Plastics 160 mg/cm^2	Plastics 840 mg/cm^2	Plastics 1000 mg/cm^2	γ-ray energy evaluation by comparing with E4.
E4	$^7Li_2{}^{11}B_4O_7(Cu)$	Plastics 160 mg/cm^2	Plastics 840 mg/cm^2	Plastics 1000 mg/cm^2	Deep dose evaluation

Appendix 2. Model number format

The model number of the TL Badge Hanger is constituted as follows;

```
U D - 8  8  7  A  (H)  1  -  T
└──┬───┘  |  | └┬┘  |    |     |
   |    (i)(ii) | (iii)(iv)   (v)
   |            |
Common        Common
term          term
```

(i) Type code

5 ------ Open type

7 ------ One-badge closed type

8 ------ Two-badge closed type

(ii) Front wall thickness code (Refer to the figure below.)

(iii) Nylon strap code

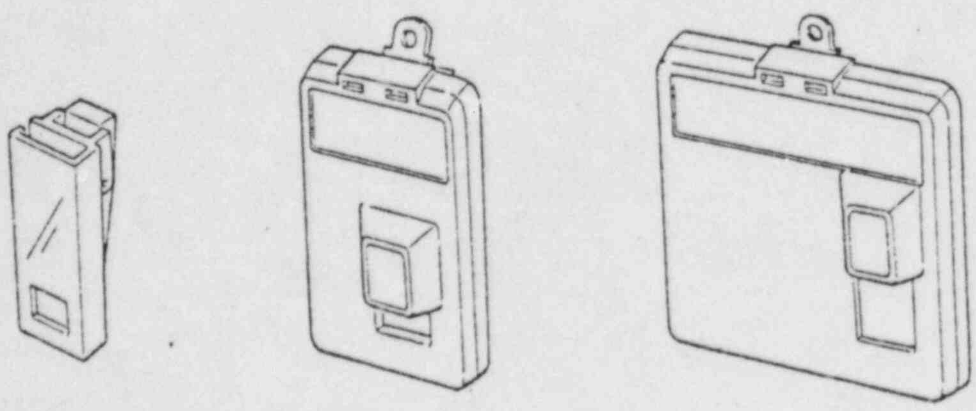
H ------ Nylon strap provided

(iv) Special code

A serial number is assigned to the special specifications hangers.

(v) Color code

T ------ Transparent



(a)One-badge open type

(b)One-badge closed type

(c)Two-badge closed type

Fig. 1 Typical appearance of TL Badge hanger