PRNC — 191 PUERTO RICO NUCLEAR CENTER THERMOLUMINESCENCE DOSIMETRY IN NORTHWEST PUERTO RICO By Arthur M.B. Block, Richard G. Clements, Luis Ivan Rosa, and Felix Santos July 1, 1975 OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT NO. AT (40:1)1898 POR US ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION ---Page Break--- THERMOLUMINESCENCE DOSIMETRY IN NORTHWEST PUERTO RICO By Arthur M.B. Block, Richard G. Clements, Luis Ivan Rosa, and Félix Santos Terrestrial Ecology Program, Puerto Rico Nuclear Center, Caparra Hgts. Sta., San Juan, P.R. With contributions from: Mario D. Banus, Marine Biology Division, Puerto Rico Nuclear Center, Mayaguez A. & M.N., Mayaguez, P.R. Robert Munson and Jones Parrish, Isotope Project, Puerto Rico Nuclear Center, Mayaguez A. & M., Mayaguez, P.R. Bagardo Hernandez*, Rolando Moquera*, and Karl Prado, Radiological Health, Medical School, University of Puerto Rico, Medical Sciences Campus, U.P.R. (Radiological Health Program) Administered By Dr. E.T. Agard, Puerto Rico Nuclear Center, Caparra Hgts. Sta., San Juan, P.R. In partial fulfillment of requirements for the degree: Masters in Public Health, Radiological Health Major. ---Page Break--- Dedication Chapter I. Chapter II. ACKNOWLEDGEMENTS The Radiological Survey Introduction Stations Descriptions Experimental Design Results and Discussion Statistical Variation of CaF:Dy Dosimeters (TLD-200) Response Under Laboratory Conditions. Introduction and Experimental Design Rejection Parameters for Field Dose Determinations. Extrapolation and Interpolation of Calibration Curve Caveat Lector Computer Program, TIDCALC (FORTRAN IV) for Dose Rate Calculations, Pair Value Rejections and Field Data Cross Referencing. Output Data from TIDCALC for All Stations and Station Locations. ---Page Break--- Dedication: This contribution is respectfully dedicated to Dr. F.G. Loman, Associate Director, Puerto Rico Nuclear Center, for his help and advice in its formulation and execution.

ACKNOWLEDGEMENTS In a program of the scope described herein, there are many

contributors, not all of whom can be considered directly responsible for the program, but without whom, the program could not have been developed to the scale described. Among these we cite the following: Puerto Rico Water Resources Authority (PARA), Nuclear Power Development Division directed by Dr. Juan Bonnet, and supporting staff Raul McClin, Rodolfo Gauthier and Engineers: Gramaiges and Mejías offered helpful suggestions and provided interagency contacts. The RRA provided all equipment, supplies and support for personnel for the completion of this work. Eng. Daniel Lebrén Pitre, M. Nucl. Eng. helped in developing techniques suitable for local application and carried out some early development alternatives related to the technique. PRC, Dr. Aviva Giteadl, Nuclear Engineering Department, made several helpful suggestions and provided several important references for study. Field station emplacement and instrumental security could not have been established without the help of the following people: 1. Gilberto Inarraza, Puerto Rico Ports Authority, Port Director, Arecibo Airport, Arecibo, Puerto Rico. 2. Engineers John MacGregor, Glenny Marshall and Dr. Woody Harris, Fgro Engineers, Barceloneta Temporary Station, P.O. 11427, Barceloneta, Puerto Rico. 3. Field Manager Victor Candelaria, Puerto Rico Power and Light (Autoridad de Puentes Fluviales), Florida Adentro, Puerto Rico. Eng. Rubén Ranos, Hydroelectric Power Station, Dos Bocas, Puerto Rico, 5. Engineers, Mereado and Gil Serrano, Puerto Rico Aqueducts and Sewers Authority, Arecibo and Charcas Hondo Stations, Arecibo, Puerto Rico. ---Page Break--- Supervisors: Carlos Acevedo and Roberto Garefa, Puerto Rico Power and Light (Autoridad de Puentes Fluviales), Quebradillas, Puerto Rico. Finally, we must acknowledge the high level of support in data received from Dr. Severino Ramos, Director, Piedras and several of his operational staff Ms. Viva Marqués, Mr. Fausto Verges, Mr. Miguel A. López and processing work which we received from Computer Center, UPR, Ric Pit members: ---Page

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Robert Munson Janos Parrish late I. Rosa ona Félix Santos ---Page Break--- A, Introduction ‘Thermoluminescent dosimetry (TLD) has been described most succinctly by Cameron, Suntharalingam and Kenney (1968). The idea ‘that ionizing radiation damage in doped crystal material could be used as a basis for radiation dosimetry appears to have originated with Daniels (1950). ‘The basic physical phenomenon which is used for TLD can be adequately described by a crude crystal model as follows: Ionizing radiation impinging upon certain crystalline material can create meta-stable states above the ground state (valence band) and below the conduction band and can liberate electrons which can populate these states. Subsequent annealing of the material causes ‘the electrons to return to the ground state (valence band). This repatriation of electrons is accompanied by the emission of visible light of frequency determined by the energy difference between the metastable state (trap) and the valence band. ‘Thus, the amount of radiation which has been received by the material can be inferred by measuring the amount of light emitted (TL) by the material upon subsequent annealing. This technique has evolved through a series of studies using materials such as lithium fluoride (LiF) (Daniels, Soyd and Sanders, 1953), calcium fluoride containing small amounts (≤ 1%) of manganese (CaF_2:Mn) (Ginther and Kirk, 1957) and more recently, calcium fluoride doped with small amounts of dysprosium (CaF_2:Dy) (Lindeken, Jones and McMillen, 1971; Lebrén, 1974). ---Page Break--- In October, 1973, the Puerto Rico Water Resources Authority sought the initiation of studies aimed at determining background radiological characteristics of the northwestern quadrant of Puerto Rico. Some of the studies were required for supporting data for the environmental report submitted as part of the licensing procedure in the establishment of thermonuclear electric power generation.

facilities in Barrio Islote, Arecibo, Puerto Rico. (Fig. I). Previous studies of radiological characteristics of the area include the "Acroradioactivity Survey and Geology of Puerto Rico (AM9-1)" (Mackalior, 1966) which consisted of mapping the radioactivity emanating from the surface of Puerto Rico using sodium iodide sensing equipment in an airplane flying at an altitude of 500 ft. The results are expressed in counts per second and provide useful comparative levels for radioactivity observed in various sections of the Island. The only thermoluminescent TL studies yet undertaken in Puerto Rico in conformance with Environmental Protection Agency requirements that the dose measurement be made at a height of 3 ft. were those undertaken for the environmental report of Aguirre, Puerto Rico (Westinghouse Electric Corp., 1972), and the FRNC preliminary data evaluation for the environmental report of Islote (Puerto Rico Water Resources Authority, Ag7h). Estimates of human dose equivalents in Puerto Rico have also been made and partially checked using TID (Lebrén, 197). ---Page Break--- Station Descriptions The stations selected for study were believed to be located in directions in which natural (or accidental) plant emissions from Islote would travel. Thus, the preliminary data base could be useful baseline data for comparison with measurements obtained during nuclear plant construction at Islote, or after such a plant was put into operation. The low-lying vegetation, tree bole direction, as well as the directions assumed by wind-swept palm boles all indicated low elevation wind direction in the prevailing onshore trade wind directions. Thus, wind currents were assumed directed predominantly toward the western, southwestern, and south-southwestern parts of the island. Subsequent wind rose data taken within the proposed exclusion zone have supported these observations in full, at all altitudes (Puerto Rico Water Resources Authority, 1974). The full station descriptions including the approximate distances from the

proposed plant site at which dosimeter pairs were placed is shown in Table 1.1. All station locations except Barceloneta, Florida Adentro, and Islote were located in prevailing wind directions from Islote. Barceloneta and Florida Adentro lie in directions off the principal wind vector directions, but data from these areas can be useful for comparison with usual climatological conditions or aberrations in the usual air mass flow. Thus virtually complete land-side dosimetry was carried out. The relative locations of the stations can be inferred from Fig. IT. ---Page Break--- ©. Experimental Design The commercially available Harshaw-2000 TLD reader was the basic instrument used with CaF: Dy dosimeters. This instrument consists of two parts. The detector part has a heating planchet on which the 3/4 x 1/4 inch square dosimeter is heated for a given period of time between carefully maintained temperature limits. In the experiments carried out, the heating cycle was for a 30 second period, with initial heating of the platinum planchet from 10°C to 240°C in approximately 10 seconds followed by approximately 20 seconds at the 240°C temperature level. All calibration and field dosimeters received precisely the same temperature program described. The light emitted by the dosimeter upon heating is sensed by a photomultiplier tube. The second part of the instrument measures the current from the photomultiplier tube and integrates it over the thirty second temperature program. Thus the TL read by the "integrating picoameter" is in photomultiplier charge or current-time units. These current-time units can only be related to the radiation dose received by the dosimeter if the machine is calibrated using dosimeters exposed to precisely known ionizing radiation doses before the field dose is accumulated. The calibration of dosimeters was carried out using a Cs-137 source from a known distance (75 inches) from the dosimeter which was packed in a black plastic bag. Details of the PRI Cs-137 standard source activity determination can be

obtained from Mr. Santiago Gémez, Health and Safety Division, Puerto Rico Nuclear Center. Inference of source dose was obtained ---Page Break--- ‘from the fact that on Nov. 25, 197, the source dose at 75 inches was 7.8150 aR/hr. Dosimeters were calibrated by exposing them to the Cs-137 source for three different periods of time estimated to give doses which upon readout would show TL's in the range in which field exposed dosimeter TL's lay. Conventional exposure times were between 11 and 72 minutes. ALL TL readouts, both on field exposed and calibration exposed dosimeters were carried out with dry nitrogen gas purging of the detector system. This refinement is absolutely necessary when low dose (background) dosimetry is undertaken. Pre-calibration of dosimeters was necessary both before field placement and before readout. A typical exposure cycle was as follows. The dosimeter was annealed for 1 hr. at 400°C and exposed to the first calibration dose. It was then maintained in lead shielding (1 1/2 inches) for 24 hours and then annealed at 80°C for 15 minutes. After cooling, it was read out over the 40°C - 240°C temperature program. The same cycle was repeated for calibration doses using two different Cs-137 source exposure times, each of which was different from the first exposure time. When the dosimeters were annealed and placed in field mounts for a minimum field exposure duration of 2 days. The field packs for mounting the dosimeters consisted of ultra low background polyethylene neutron activation vials. Two dosimeters separated by a short styrofoam plug were placed in each vial with a small piece of paper containing identification or cross-referencing data. The vial was tightly sealed and enclosed in a layer of black plastic electrician ---Page Break--- First, the CaF_2:Dy chip is not equally responsive to ionizing radiation of all types and all energies, and is mainly responsive to gamma and x-rays. Second, the TL emission of a CaF_2:Dy dosimeter tends to fade with time. One alternative to the ionizing radiation

energy problem is to enclose the CaF: Dy dosimeter vial in a lead sheath of .002 inches diameter and a tantalum sheath of .01 inches. This alternative could not be undertaken within the time permitted for the measurements, though a correction involving the ratio of TL for a typical TWD mm with and without the sheath has been written into the computer program. Thus all future data obtained using the sheathed configuration can be compared with the data presented herein. A somewhat more conventional procedure is to assume that the energy distribution of gamma and x-rays in the environment is very nearly the same at the 3 ft. level over all time and that a simple factor multiplied by the measured Co-137 equivalent will correct for the change in energy response and stopping power of CaF:Dy when exposed to natural background radiation. Thus, multiplication of Cs-137 equivalents deduced from the observed TL after field exposure by the factor 2.5 yields the effective dose absorbed in mR (Lindeken, Jones and McMillen, ign). Two different approaches may also be used for the fading correction. Lebrin (1971) applied a 20% increase to the measured dose based on the signal loss observed when dosimeters were exposed for 1/2 of a standard time interval and then shielded in lead for the remainder of a ---Page Break--- of the time. The measured "1/2-dose" was compared with the dose measured on dosimeters exposed for the full time interval. Alternatively, one may use a fading correction which stays relatively constant after the first 24 hours, deduced from the fading data of Derhan, Kathren and Corley (1972). Their data indicates that for exposures in excess of 20 days a correction of 164 µR is realistic for CaF:Dy. The field exposures were over periods in excess of 2 days, and many were in excess of the 33-day exposures by Lebron (1974). Thus the correction referred to as the "Derhan correction" in this report is an upward adjustment of 164 of the indicated dose. Results and Discussion the results are

summarized in Tables 1.2 - 1.5. The measured dose rates which passed the rejection tests applied in computer program ‘TUDCALC are grouped according to the station in which the pairs were located. These tables also give percent uncertainty in dose rate as calculated using the analysis in Chapter II. The mean dose rate for all dosimeter pairs associated with a particular station and the estimated uncertainty in the mean of the two values of each pair plus the mean estimated uncertainty for all the pairs is also given. The values for Arecibo indicate rather low dose rates. Data collection in Arecibo was difficult because of the amount of pilferage, vandalism, or other losses of dosimeter vials. Even dosimeters were set out for extended periods. The area from which the data were collected was approximately two square miles. Highest and lowest doses are reasonably close and the standard deviation of the pairs over the surveyed is not large (Table 1.6). We ---Page Break--- The four stations: Isabela, Arecibo, Arecibo Airport and Barceloneta gave substantially the same dose rate of 100-200 eps during the AWS-1 survey (Mackallor, 1956), and within experimental error, the mean readings at the 3 ft. level reflect similar dose rates for those four stations. The mean TLD reading for Florida Adentro, Charco Hondo and Dos Bocas also are consistent with the ARMS-1 survey as are the Lares, San Sebastián and Quebradillas stations. The Mayagüez station exhibits a dose rate which is still reasonable compared with ARUS-1 within the limits expressed by the mean standard deviation (Table 1.6), though slightly on the high side. It is suggested that this may be due to the fact that the area surveyed in Mayagüez was rather limited and a more widespread survey of the Mayagüez area such as the ARIS-1 survey might reveal a somewhat lower TLD dose than is indicated here. It should be noted that the highest dose rate recorded during the TWD survey of Aguirre was at Sabana Liana (11.-11.5 Micro-rad/hr) and the lowest was

recorded at a dairy north of San Felipe in this region (7,107.5 Micro-red/iir.). In no case did any of the data taken in the present study exceed about 17 Micro-rad/hr, with average values substantially below this value. The TID dose rate profile is, perhaps, better visualized by referring to Fig. TT. The route numbers of highways and secondary roads along which dosimeters were placed are given in parentheses. The large type numbers beneath the station names are the mean doses for the stations sampled; the areas encompassed by a station can be approximated by subtracting the values given for station sampling distances in Table 1.1. Throughout this analysis, the fading correction preferred has been that given by Dexham, Kathren, and Corley (1972) rather than

Lebron (A974) because the following experiments indicated that even heavy lead shielding, when used under well-controlled conditions, may not keep the CaDy dosimeters from being exposed. At each station, three lead blocks were stacked up. Each lead block was circular, 6 inches in diameter and 3 inches thick. The center block had a small hole drilled through the center just wide enough to contain a vial in which were two dosimeters. These setups are referred to as "STD" in Appendix II. At the beginning of a particular time interval, a pair of dosimeters was placed inside this shielding and retrieved when the other dosimeters in the station were retrieved. Sometimes the indicated dose of these “shielded” pairs was as high as 1 Micro-rad/hr and was never less than 0.7 Micro-rad/hr. Thus, corrections based upon maintenance of dosimeters with lead shields after being exposed for 1/2 of the exposure period seem to be subject to some uncertainty. These results also indicate that the assumption in the error analysis (Chapter II) that at zero dose, zero TID, will be observed may not be at all correct. It is clear that uncertainties in the lower dose measurements (approximately the same order as the measurements themselves)

indicate that regression data used to test higher measured field doses is suspect when attempts are made to extrapolate these for use at the lower dose. In view of this observation, it is felt that future measurements ought to make use of statistical sorting of dosimeter pairs or trios such as that used by Lebrin (197), or ultra-low dose data for error and rejection analyses should be taken. ---Page Break--- Fig. TZ. Map of Puerto Rico Showing the Location of Barrio Islote, the Proposed Nuclear Plant Site and Distance (in Km.) to Major Coastal Towns and Cities. ---Page Break--- PUERTO RICO WATER RESOURCES AUTHORITY NORTH COAST NUCLEAR PLANT UNIT NO. 1 BACKGROUND RADIOLOGICAL SAMPLING LOCATIONS AND PROPOSED SITE FG 281 ---Page Break--- Fig. IT. Map of Northwest Puerto Rico Showing Approximate Station Locations, Roads and Highways Along Which Dosimeters were Placed (in Parentheses), and Mean TID-Recorded Doserates (Large Type Beneath Station Names). ---Page Break--- ---Page Break--- Table 1.1 Station Arecibo Arecibo Airport Barceloneta Charco Hondo Dos Bocas Florida Adentro Islote Laree Mayaguez, Quebraditas San Sebastian 15-20 B22 an-e5 Direction from WoR0-1 Site WWF sw BSE - 8 WoW = Si ssw ser -8 Within Exclusion Zone sw ww « wow ---Page Break--- Table 1.2 cums, ae tie St, Bie, “SSE min ar Ente, (ene Arecibo + 3% 6.23 +h 2 21g 185 Airport 6.630 + 20% 8.09, +1 009 6.665 20h 7179 1h 13.634 1 9.598 16 8.7 1% 22.168 1h ie 4 8.708 Wh 6.12 1S 6.057 1 6.089 1% 7.694 1% Barceloneta, 5.758 + 2m 6. Bs iB 8 6.269 ah + Using the Lindeken-Denham corrections to the measured dose ---Page Break--- Table 1.3 Estimated Mean Mean Estimated Uncertainty Dose Rate Uncertainty Dose Rate Micro Dose Rate t 4 9.98 +i% 1% ih ah Dos Hocus + 8.95 119% Florida + m6 sam Raentre BRUSRRRSRLE BRARRA + Using the Lindeken - Denham corrections to the measured dose. ---Page Break--- Table 1.4 Islote 10.607, 8.906 9.696 8.271 Wh 1.825 Gh etd ct 8.260 a 81460 1% 9.429 1h 9.227 xg 11.507 4.221 2 Tares: 1-559 + 20% 10.74 41% 8.594 18 7.960 1b 11.29, ls

7.833 1% kg 1 11.553, 1h 13.085 1 a0tli90 im e225 cred 9.061 Ft 16.982 ws Mayasues 8.612 ax 9.32 +186 1.235 2, ek 20h 8.650 wh nize i io.t03 xm 12.463 a 4 sing the Mndeken - Denha corrections to the measured dose. ---Page Break--- able 1.5 Calculated Dose Rate® Station Micro uebraaitias San Sebastian asa Estimated. 10.67 Mean Estimated Uncertainty Dose Rate +t « Using the Lindeken - Denhan corrections to the measured dose. ---Page Break--- a et (02-00T a6 conte seer onsasoy, 4 we ‘00-008 Secor appret gear serryrezaerd a Ag't 006-002 igor oeL"et oun’ upriewaes os a we 005-05 nurot EIT esgre soe 9 out 0-008 68 eoo'tt we'9 swo0g s0q 6 get 08-002 66 ert eh opto oozwuy a eve ose-008 49° 196" 910"9 oxsuapy WPHOTS 4 60 03-00 19 6leh eres ‘vouopeora, x wre 008-00 60"e negret 1s0"9 qaodsty oarooxy ‘ ert (002-00T 9 mee art oayoery a et 02-00% we wos" ee"h syorst (voysar3ea) SAAT THERE OFA gE OT TT OT Sea COFRTS ‘380g Jo suoyyuaxosgg oTHUTS Jo /squmOD “90H ‘29m 9800 ‘S9y 9800 oxyeg Jo "ou UOFaBTASG “Pas WueR —O8OT T-SHEY co *sa9 3800] Ort ores ---Page Break--- (CHAPTER II SOATISTIONL VARIATION OF CaP, Dy: DOSIMETER (710-200) RESPONSE UNDER LABORATORY CONDITIONS wy Artinar MeB. Block Marto D.banus Bagardo Hernéndez uéndes? Rolando Mosquera Moreno? Karl P. Prado! ant Pélix Santos Hernéndez Experimental work carried out in partial fulfillment of the Master in Public Health Degree offered in Radiological Health, Medical Physics Program, Dr. E. 7. Agard, Director. ---Page Break--- Introduction and Experiment Description In order to determine the uncertainty associated with car2:Dy (11p-200) dosimeter data for non-statistically-sorted groups, the following experiments were carried out, A group of 10 dosimeters (5 pairs) were ‘exposed to know doses of gamma radiation using the PRNC Co-137 source. ‘The first dose selected was approximately 2.75 mR, the second 7.75 mR, and the third 13.25 mR. The 10 dosimeters were taken through ‘the following cycle 5 times at each do ‘Ames at 400% for 1 hour prior to irradiation, 2. Irradiation,

3. Storage for 2b hours in lead shielding. 4. Anneal at 80°C for 15 minutes prior to thermoluminescence readout. 5. Readout over @ 50°C to 20°C temperature range. Since the dosimeters are light sensitive, care was exercised to exclude visible light during handling and processing. The variation within the group of 10 as a function of dose was then evaluated. The variation of dosimeter pair values was also of interest since field measurements were undertaken with pairs of dosimeters rather than with single chips. The mean response per dose of single dosimeters and for dosimeter pairs was of interest at the three doses because field doses below the lowest dosimeter calibration dose value were inferred by linear extrapolation from the low dose value to zero dose (zero TL). Likewise, the doses which were above the highest calibration dose were also inferred from extrapolation using the intermediate and the highest dose thermoluminescence (TL) response points to obtain TL response vs dose slope. This slope was presumed to hold at higher field doses provided the doses were not excessively high (i.e. less than twice the highest calibration dose). ---Page Break--- The raw TL responses for the 10 dosimeters in the five experiments at each dose are presented in Tables 1, 2, and 3. Dosimeter pairs are taken to be consecutively numbered (i.e., 1&2, 3&4, etc.). The arithmetic mean TL response of all 10 dosimeters, and the standard deviation on a single TL response from the entire group at each exposure is also tabulated. Also, the reproducibility of TL response for all 10 dosimeters exposed 5 times to the same dose is evaluated by calculating the mean TL for the 5 equal dose exposures and the standard deviation of a single TL response at a given exposure in the 5 exposure series. This latter quantity is probably most important in determining whether or not pairs of TL values for field exposures ought to be rejected on the basis of failure to lie within reasonable statistically variable limits: B. Rejection Parameters for

Field Dose Determination Implicit in any criterion for rejection of pairs of T-values is an acceptance of some absolute calibration value or a group of absolute calibration values in the absence of a known scaling factor (Linear or non-linear). Our criterion for rejection of field dosimeter readings is based on the TL-indicated Cs-137 equivalent dose in aR and our assumption of absolute values involves an acceptance of the Cs-137 standard source values given. A cursory inspection of the standard deviations of single chips exposed to particular levels of radiation (Tables 1, 2, and 3) indicates that, with the possible exception of the highest dose, a simple differential propagation of uncertainties (Daniels et al, 1952; Pugh and Winslow, 1966) in the pair means is a slight oversimplification of the problem of estimation of uncertainties were it not for the fact that no weighted function is used to calculate the pair means. A simple arithmetic function is used which does not imply differential multipliers other than unity. The calculated propagated uncertainties in

TL using pairwise averaging are given in Table 4 as a function of dose, with the average uncertainty for the pairs. In practice, the uncertainties calculated can be used by fitting the dose to the TL values using a known functional dependence. In the low dosage region, this functional dependence is very nearly linear. Thus the TL per unit dose are .W52 and .49h for the doses of 2.71, 7.676 and 13.158 aR respectively. Assuming zero TL with zero dose, a convenient equation for dose as a function of TL is: $D = e^{(a + b * TL)}$ in which D is the dose, TL is the measured thermoluminescence and a, b, and c are constants. Using the dose and TL values from Table 4, a, b, and c are .007, -.027871 and 2.225703 respectively. Of greater importance is the variation of uncertainty in TL readings with dose changes and variations in uncertainty of indicated dose with changes in observed TL for the field-exposed dosimeter. In this case,

Convenient equation which takes into account non-linear changes in uncertainties is a quadratic equation for ΔTf, the deviation in the thermoluminescence associated with an observed TL level. Expressing this uncertainty as a fraction of the measured TL is somewhat more useful in the actual data analysis. The percent uncertainty in pair average for the three Cs-137 doses: 2.742, 7.676, and 13.158 aR are calculated to be: 22.09%, 14.90%, and 4.816 respectively from the data in Tables 1, 2, and 3. ---Page Break--- If the equation: (1) Y is the percent uncertainty in measured TL (TE) and a, b, and c are constants, is used, no assumption needs to be made for the uncertainty at zero exposure (zero TL). The calculated values of a, b, and c from the data in Table b are: 0.002783, -0.019297, and 0.249039 respectively. The two regression equations - one for D and the other for Y provide a basis for estimation of the uncertainty in sample dose of an employed dosimeter - ΔD. Thus if D = D(TE), (3) ΔD = (4) Om recognizing that this is a first approximation to QD since the weighting function for ΔT: + (jt) from equation (2), in this case, is not unity. (5) Qp = a + bT + cΔR. Pair values can now be rejected on the basis of whether or not the values of average dose of the pairs plus or minus some adjusted value of ΔD inferred from (1) overlaps the individual doses inferred from the measured TL values. The quantity ΔD with a scaling factor of unity ought to be a sufficient criterion provided that the coefficients a, b, and c and d, e, and f derived from experiments such as the one described are "double-blind" in nature, or that the dosimeters used to measure field dose are subjected to some sort of initial laboratory statistical selection before field use, by a single field investigator. Assuming that the parameters characterizing the readout of dosimeter TL, i.e., heating cycle, nitrogen flow, and annealing times are ---Page Break--- the same for both field and controlled exposure measurements the data in Tables 1, 2, and 3.

is sufficiently general for field-correction applications such as pair value rejections. Thus (5) Ad = (021654 TH - wossthe H + 2.205703). ATE in which JE is the mean value for a dosimeter pair, V is calculated from equations (2) and (6)47E = (v) - (HE). As an illustration, consider what the estimated uncertainty in D, AD, would be if a thermoluminescence of 1.245 resulted from the mean of a field-pair measurement. From Table 4: TE 0.275 b and c are known, so AD of an inferred exposure is calculable. In order to use this uncertainty data with other TE measurements on a field-exposed dosimeter, the derivation of AD as a function of TE is the most useful equation of all and it may be readily inserted in a computer routine for testing the data of dosages calculated. Thus Table 5 gives AD as a function of SL near three known points. Using the same type of regression equation as before, a general expression for the uncertainty in indicated dose as a function of indicated dose may now be evaluated: (Dad = woe eg gt ry) in which the subscript J refers to dose indicated using the TL observed for a field-exposed dosimeter with calibration data of TE as a function of the dose. Relating the three constants from the data in Table 4, (8) Ad = .023835 ny^2 + 57655. This equation is the basis for estimated uncertainty in dose when the dose is derived by interpolation of calibration dose vs TL points. -6- ---Page Break--- C. Extrapolation and Interpolation of Calibration curves The inference of doses from field measurements yielding TL values which lie between two known calibration points presents no serious obstacle. Lebrén (1974) has used the statistics sorting (selection) method with dosimeter handling procedures currently in practice in the PRNC Terrestrial Ecology laboratory facilities. Though it is unclear what statistical rejection procedure was used in his work, assuming a linear function of the log of TL response versus calibration dose, his method has some advantages relative rapidity with which many samples can.

be processed, and his field dose uncertainty estimate: fare approximately 30%, not considered a large uncertainty for the type of field work which was carried out. ‘The data in Tables 1, 2 and 3 do show that a linear interpolation of calibration data can be used to derive unknown field doses from measured TLs without introduction of excessive errors, provided doses larger than approximately 15 mCi of Cs-137 equivalent are not encountered. Using a standard 30-50 day exposure for the characterization of local environmental radioactivity Cs-137 dose equivalents as high as 1B mR have been infrequently encountered. In areas of high dose rate, shorter field exposure times can be used to maintain the lower uncertainties introduced by the linear interpolation approximation. Another alternative in this case is to select chips which have lower sensitivity, since the characteristic can vary widely from chip to chip. Our experience indicates that overly long exposure times increase the risk of vandalism of dosimeters placed in field stations. Furthermore, long exposures may be impractical for use in environmental monitoring under future Nuclear Regulatory Commission (NRC) policy commitments. -T- ---Page Break--- Extrapolation of calibration dose versus TL curves to doses below the lowest TL observed in the Cs-137 calibration is difficult. It is not clear that the measurement techniques used in this study warrant the assumption of zero TL for zero dosage. Thus linear or first order slope-correction derived curves from zero dose up to the lowest calibration dose may be subject to errors in TL approaching the values of the indicated dose. Some of the experiments described in chapter 1 suggest that an uncertainty of 100% is not unreasonable if the linear extrapolation is employed. ‘The additional assumption that the lowest calibration dose point is fixed and absolutely correct for the purposes of zero-to-lowest-dose slope determination is not good. However, in the absence of reliable very low dose data, this approach has

been used and the values which result should be regarded as trend indicators, unsuitable for all but the most qualitative of interpretations. D. Cavest tector ‘The analysis presented above is a practical approach to a field research problem. The confidence which can be placed in single field Measurements carried out at different times (and frequently at different Locations) is never very great. There simply is no substitute for the classic £ and t tests when data significance is at issue. Such tests generally need considerable data taken over the same period of time, using substantially the same techniques in order to be conscientiously applied. In this, the initial survey of Northwest Puerto Rico, resources of manpower, instrumentation and (most important) time did not permit more than a general description of radiation levels using TLD. Presumably, future measurements of background radioactivity will aim to build ‘upon the experience obtained herein. Analysis of variance using accepted techniques should be high on the list of priorities in such future studies. ‘Table 1 2.741 ae “TORETBORTE Tea oS Str ver | Posineter # in Bogue 2 2 3 Exposures Single Exposure, a 1.183 2.549 1.600 1.407 1.285 1.605 + 0.550 2 0.953 1.0ke 1.128 1.261 2.269 Las 5 0.238 3 L217 1.640 1.279 1.314 1.578 1.366 0.234 4 2.3MB 1.468 1.034 1.358 1.288 2.303 0.1m 5 2.040 2.626 1.438 1.157 1.289 1.310 £ 0.232 6 0.760 1.663 1.116 1.28 1.377 1.207 + 0.306 1 0.986 2.345 0.9m 1172 1.228 Lak + 0.261 8 1.065 1.302 1.089 1em 1.2 1.168 + 0.110 9 2.312 0.207 2.013 1.131 1.336 2.082 + Oto do 1.47 2,001 1.073 1.151 1.359 12M 0.23% Mean Response (Intra-group Ton-sorted 10s. 1.383 1.207 1.26 1.298 St. Deviation of a single Dosimeter TL in the

Group 40.176 £0.595 20.206 10.09% 40.131 Table 2 Dove: 7.676 aR. ILsReapanae aan oF 3 Sea Deviation Dosimeter # for Exposures 2 2 3b Exposures Single Exposure a h.o6e 3.6 3.7 3.763 3.8868 3.770 ¢ 0.21h 2 3.979 2.577 Mobs 3.557 3.06 3.4m + 0.603 3 3.T15 2.730 3.936

3.296 3.203 3.356 + 0.48 4 3.904 2.65 3.977 3.658 3.608 3.564 40.534 5 3.716 2.596 3.910 3.376 3.176 3.359 + 0.538 6 3.705 2.593 4.013 h.o7e 3.637 3.660 + 0.643 1 3.52 2.005 3.792 3.065 2.005 3.196 0.57 8 3.661 2.793 4.092 3.030 3.182 3.34 + 0.532 9 3.689 e7la 3.692 3.518 3.018 3.338 + 0.kes 10 3.754 eThr 3.815 4.00 3.b52 3.578 £0.58 Mean Response Setar 3.706 2.722 3.908 3.601 3.306 Sta. Deviation of a Single Dosimeter in the Group 40.262 £0.45 40.134 0.368 40.315 ---Page Break--- The Response Yield of Dosimeter # for Exposure 2 uw L 5.646 5.638 5.832 5.405 5.79% 663, 2 5.899 5.551 5.631 5.337 5.797 5.643, 3 5.725 5.73 5.802 5.388 5.746 5.679 4 6.12 9.682 5.94 5.633 6.112 5.908 5 5.694 5.577 5.879 5.229 5.820 5.640 6 5.839 5.643 5.455 5.668 5.902 5.701 £0.176 7 5.521 5.386 5.620 5.797 5.534 5.572 +5 0.152 8 5.852 5.737 5.717 5.015 5.890 5.642 + 0.358 9 5.578 5.30 5.423 5.302 5.919 5.505 + 0.258 10 6.008 5.616 6.335 - 6.826 6.206 +2 0.508 Mean Response (non-sorted Intragroup) 5.79 5.587 5.761 5.19 5.937 Sta. Deviation of a Single Dosimeter in the Group £0.200 20.2h2 40.263 40.043 10.353 ---Page Break--- *dpy> pus 03 sommsodxe ot uodn posve Sle-on6tlS ——RowronStaS—Slz"OnLog'S —HBeroqtlg's — GerregTEL'S «ce OGES's «geet HS“ OZNH'E nba OBS" E ZGGroole"E EBS *OZ60G"E gas rozO9H"E —aSH"OFTAOTE hoe S12 OySqe"T 2H rOGATT — GETOFTNT'T —aROGEOR"T —ET-OSSEET —Lomozage-y HR THL'2 TOE von Se vuta co Seek SONS = ASETIATVLSNOM “S°H'H CELVOWEONE RUIN SBOENAY HIVE I 4 ota ---Page Break--- Table 5 Dose a Az a > © a a.ma 1.265 40.275 0.007238 -0.c27872 2.205703 40.606 1.616 34h 40.516 1.183 13.158 DMS 40.275 tong ---Page Break--- REFERENCES: Cameron, J. R., Suntharalingss, N, and G. 1, Kenney, 1968. ‘Thermo luminescent Dosimetry", Univ. Wisconsin Press, Madison, Wisconsin, Daniels, F., 1950. Thermoluminescence and related properties of crystals, Symp. Chem. Phys. of Radiat, Dosimetry, Tech. Command, U.S. Army Chem. Center, Maryland, Daniels, F., Boyd C. A. and D. Y, Saunders, 1953. Thermo-luminescence as a research tool.

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