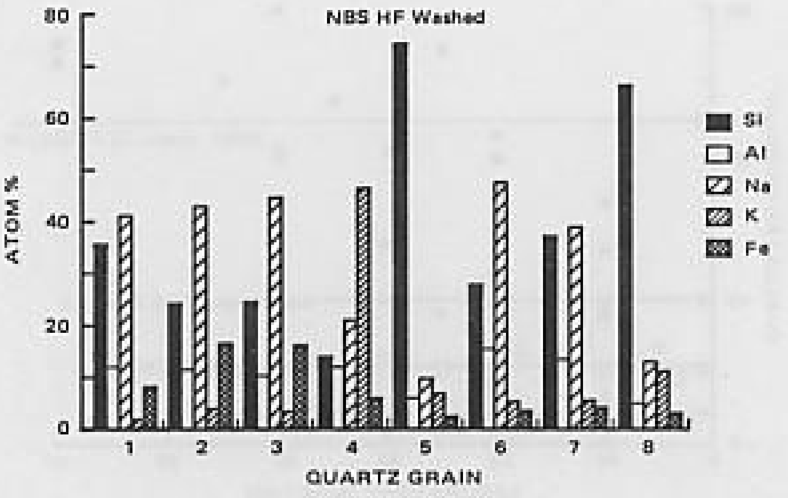

Figure 2. Relative concentrations of Si, Al, Na, K, and Fe in NBS quartz grains

size of 106 to 250 μm with a hand operated hydraulic crusher. The grains were annealed at 1090°C for 30 minutes in air and cooled rapidly to room temperature. Two of the quartz containers described above were used to contain approximately 3 g of material each. Two additional containers were filled with locally produced Al_2O_3 crystals ranging in size from 106 to 250 μm. The containers were sealed with two layers of aluminized mylar tape (Scotch Brand 350PAU302623). The containers were hand carried to the AFRRI where one pair of samples (quartz and Al_2O_3) was irradiated with a nominal 46.5 rad of 6 MeV bremsstrahlung at 70,000 rad/s using a linear accelerator (LINAC) and the second pair with 50 rad of gamma radiation from a ^{60}Co source as described in Chapter 4 Appendix 6a. Sample exposures were determined with dose-rate independent LiF dosimeters.[8]

Measurements. Measurements were made with unetched grains, 150 to 250 μm in diameter on a Daybreak Nuclear and Medical Systems high temperature TL reader. High temperature analysis (290°C peak) was performed on the AL_2O_3 , and both high temperature (integration limits 240 to 380°C) and MA pre-dose analyses on the quartz samples. Since both the Al_2O_3 and quartz samples displayed changes in sensitivity with repeated heating, aliquots of previously undosed samples were analyzed for normalization of sensitivity changes.

Results. Results of sample analyses are presented in the Table 3. The first two rows are sample measurements of the dose to quartz, the last two are normalized to the applied doses. In the case of the MA measurements of quartz, a plot of the evaluated dose versus calibrating beta-particle dose (Figure 3) resulted in a net positive slope ($p>0.975$) for the LINAC-irradiated sample. Because of this the best estimate of dose is that derived with the curve fitting procedure described above. The slope of the regression line of the ^{60}Co-irradiated sample was not statistically significant (Figure 4); therefore, the mean of these measurements is taken as the most reliable measurement. These values are given in the summary of the measurements shown in Figure 5.

None of the samples or methods of analysis showed significant differences between the high and the low dose-rate treatments. The systematically lower doses measured for these

Table 3. Results of the Study of the Dose-rate Effect

	Applied	Al_2O_3	Quartz		
			High-temp.	MA mean	MA curve fit
Doses (rad)					
LINAC	45.7	37.8 ±0.9	39.1 ±0.8	41.3 ±2.5	38.8 ±2.0
^{60}Co	50	41.6 ±1.1	42.1 ±1.3	40.5 ±2.1	39.4 ±2.2
Doses (normalized)					
LINAC	1	0.83±0.02	0.86±0.02	0.90±0.05	0.85±0.04
^{60}Co	1	0.83±0.02	0.84±0.03	0.81±0.04	0.79±0.04

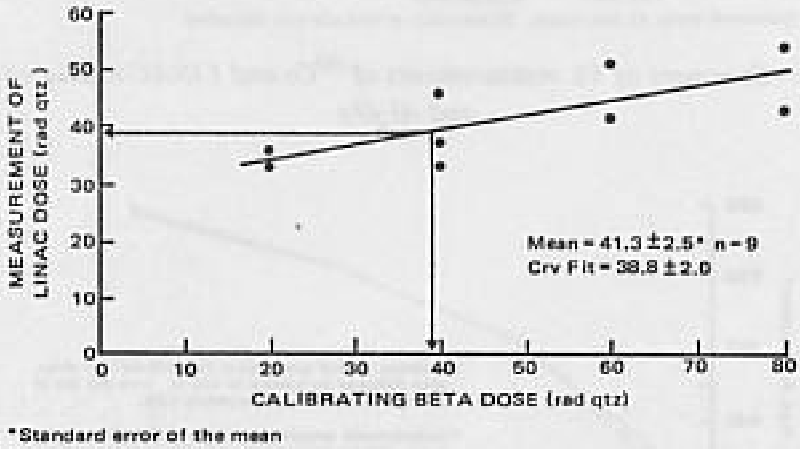

Figure 3. Pre-dose measurement multiple activation of LINAC-irradiated quartz

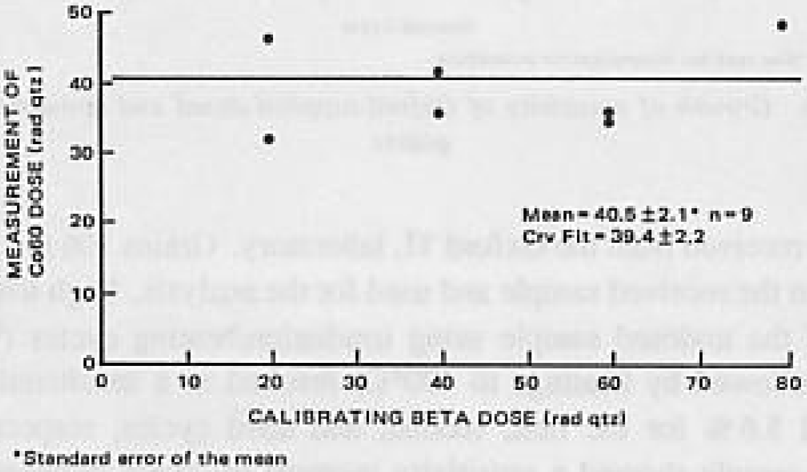

Figure 4. Pre-dose measurement multiple activation of ^{60}Co irradiated quartz

samples relative to the stated applied doses is likely due to calibration differences between laboratories or uncertainties associated with conversion of exposure (roentgens) to dose in quartz (rad) in the original irradiated samples.

Utah Analyses of Oxford-dosed Sample

Two portions of BDH quartz, one annealed and dosed with 400 rad and the other annealed

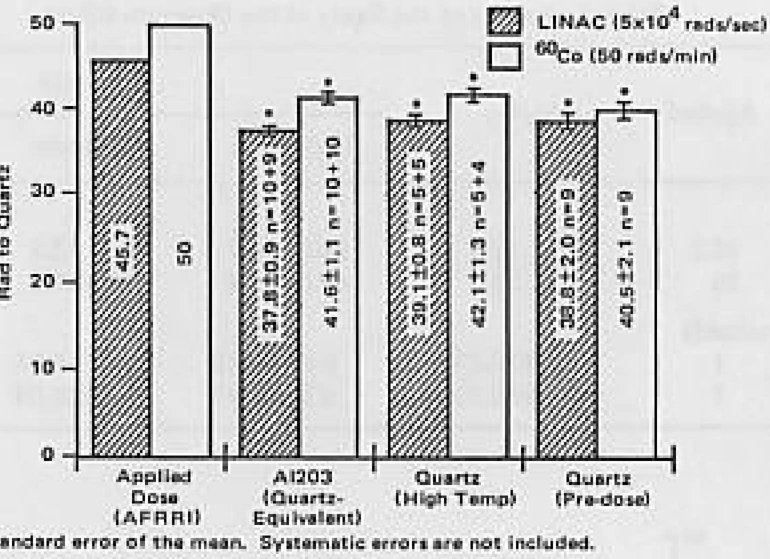

Figure 5. Summary of TL measurements of ^{60}Co and LINAC-irradiated quartz and Al_2O_3

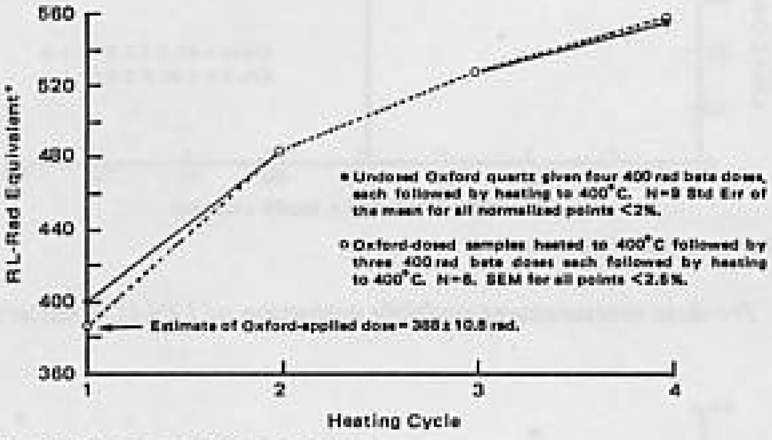

Figure 6. Growth of sensitivity of Oxford-supplied dosed and non-dosed BDH quartz

but nondosed were received from the Oxford TL laboratory. Grains 106 to 150μm in diameter were separated from the received sample and used for the analysis. High temperature analysis (340 to 380°C) of the undosed sample using irradiation/heating cycles (^{90}Sr beta-particle doses of 400 rad followed by heatings to 400°C) resulted in a sensitization of the sample of 19.3, 10.5, and 5.6% for the first, second, and third cycles, respectively (Figure 6). The Oxford-doses sample showed a sensitivity increase of 23.6% between the glow of the Oxford-applied dose and the subsequently applied 400 rad ^{90}Sr beta-particle dose. Further increases due to the cycling procedure described above resulted in increases of 10.5 and 6.2%, values in good agreement with the undosed sample. By normalizing values from the two sets of sample to the second glow values, an estimate of the Oxford-applied dose of 386 ± 10.5 rad was obtained.

Preparation-stressed Samples

Two portions of Hiroshima University railing tile UHFS02 measuring approximately 18 mm × 24 mm × 20 mm thick with a density of 2.1 g cm^{-3} were annealed at 900°C for

16 hours in air. One of the samples was then irradiated using the ^{137}Cs gamma-ray source at UU Radiological Health Division described in Chapter 4 Appendix 6b. The other sample was not irradiated. Both samples were prepared using standard procedures, and HF-washed grains in the range of 150 to 250 μm were used for the TL analysis. To provide a control sample given an equivalent dose of radiation, the crushed material from the dosed sample was reannealed, reconstituted, and packed into a plastic cylinder with inside diameter of 25 mm and wall and base thickness of 1 mm. The length of the sample (30 mm) was adjusted relative to the density of the crushed sample to provide a cylinder of material of attenuation equal to the originally irradiated material (1.4 g cm^{-2}). The height of the plastic container was also trimmed to 30 mm. This reconstituted sample was exposed to the ^{137}Cs using the geometry and duration of exposure which had been used for the original irradiation. The outer 3 mm of the exposed surfaces were removed and nonmagnetic grains of 106 to 150 μm diameter were isolated. The grains were washed in distilled H_2O and rinsed in spectral grade acetone prior to analysis. The grains were not treated in HF.

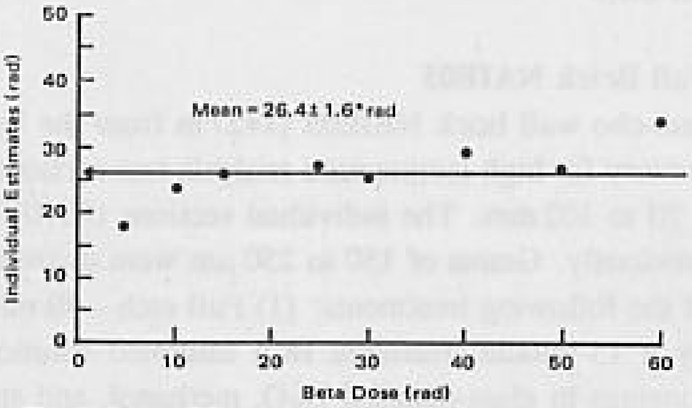

Figure 7. Preparation-stressed, irradiated sample multiple activation

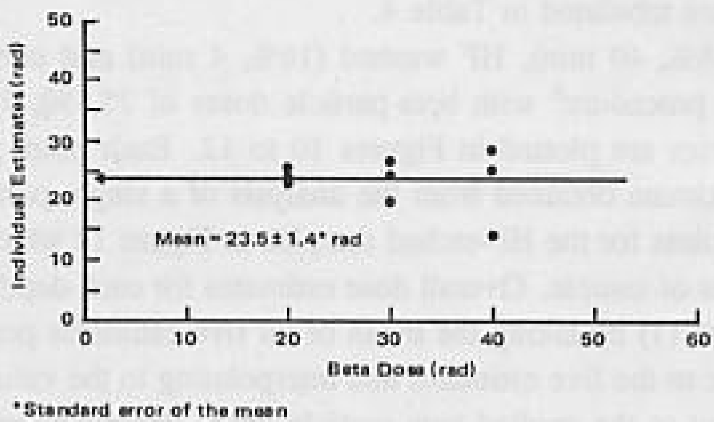

Figure 8. Nonstressed, irradiated sample multiple activation

TL Analysis. All samples were analyzed using the MA procedure described previously.[3] The results, shown in Figures 7 to 9, reveal no significant differences between the preparation-stressed irradiated sample and the irradiated control. The means for the two groups were

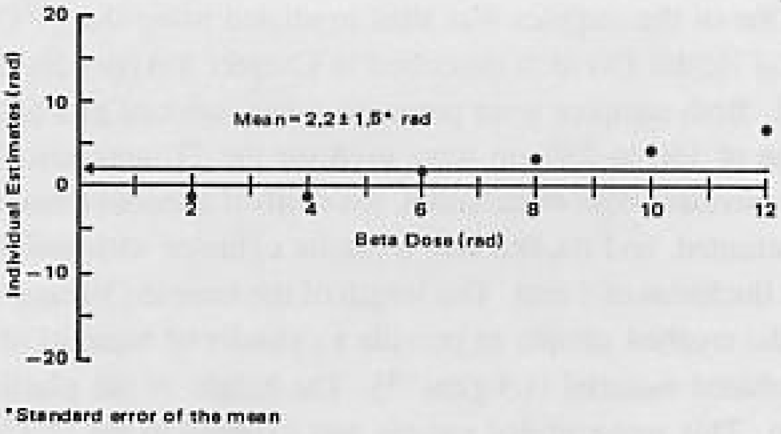

Figure 9. Preparation-stressed, nonirradiated sample multiple activation

26.4* ± 1.6 and 23.5 ± 1.4 rad, respectively. The mean dose measured for the undosed, preparation-stressed sample was 2.2 ± 1.5 rad (mean standard error), a value which does not differ significantly from zero.

Nagasaki Ieno-cho Wall Brick NAIE05

One third of the Ieno-cho wall brick NAIE05 (1427 m from the hypocenter) which was sent to the Oxford laboratory for high temperature analysis was sectioned into three portions, 4 to 36, 37 to 69, and 70 to 102 mm. The individual sections (NAIE05 A, B, and C) were crushed as described previously. Grains of 150 to 250 μm were recovered from each section and subjected to one of the following treatments: (1) Full etch - 40 minutes in concentrated (48%) HF followed by a 15-minute treatment in a saturated solution of $AlCl_3$ at 50°C followed by repeated rinsings in glass-distilled H_2O, methanol, and spectral grade acetone, (2) HF wash A - four minutes in a 16% solution of HF followed by $AlCl_3$ treatment as above, (3) HF wash B - three minutes in a 24% HF solution with $AlCl_3$ treatment, or (4) No Treatment - samples underwent no treatment other than the separation process. The starting quantities and yields are tabulated in Table 4.

The HF etched (48%, 40 min), HF washed (16%, 4 min) and unetched samples were analyzed using a MA procedure[5] with beta-particle doses of 25, 50, 75, 100, and 125 rad. Results of these analyses are plotted in Figures 10 to 12. Each point for the three figures represents the dose estimate obtained from the analysis of a single portion of sample (with the exception of the points for the HF-etched samples in Figure 12 which are each the mean values of three portions of sample. Overall dose estimates for each depth and treatment were computed in two ways: (1) by taking the mean of all five estimates per sample, and (2) by fitting a regression line to the five estimates and interpolating to the value for which the dose estimate was equivalent to the applied beta-particle dose. Results of overall dose estimates are shown in Table 5.

The grouped means for the three treatments are shown in the lower rows of the table. The overall means are in agreement for the unetched and full etched samples, but they are

*A significant slope was found in the plot of evaluated dose versus applied beta-particle dose for the preparation-stressed sample. The estimate obtained by interpolation for this sample was 25.7 ± 0.9 rad.

Table 4. Starting Quantities and Yields of Nagasaki Ieno-cho Brick Sample NAIE05

Sample	Starting quantity (g,%)		
	Bulk	106-150 µm nonmagnetic	150-250 µm nonmagnetic
NAIE05A (4-36 mm)	241.7		2.49 (1.03%)
NAIE05B (37-69 mm)	228.9	0.63 (0.28%)	2.02 (0.88%)
NAIE05C	227.9	0.59 (0.26%)	2.05 (0.90%)
	Yield (mg,%)		
48% HF 40 min			
NAIE05A	2000	143 (7.2%)	267 (13.4%)
NAIE05B	1500	134 (8.9%)	195 (13.0%)
NAIE05C	1500	108 (7.2%)	260 (17.3%)[a]
24% HF 3 min			
NAIE05A	200	29.7 (15.4%)	57.2 (26.4%)
NAIE05B	200	23.3 (11.7%)	43.2 (21.6%)
NAIE05C	200	17.7 (8.9%)	57.6 (28.8%)
16% HF 4 min			
NAIE05A	200	29.7 (14.9%)	57.2 (28.6%)
NAIE05B	200	34.7 (17.4%)	50.9 (25.5%)
NAIE05C	200	24 (12.0%)	58 (29.0%)

[a]Reetching for an additional 10 minutes resulted in final yield of 12%.

Table 5. Overall Dose Estimates for Nagasaki Ieno-cho Brick Sample NAIE05

Sample	Calculation	Dose (rad)		
		Unetched	HF wash	HF etch
NAIE05A 4-36	LIN LST	109.0± 5.6	97.2±5.5	97.4±7.3
	MEAN±SEM	97.1± 7.0	88.7±7.5	96.9±4.1
NAIE05B 37-69	LIN LST	65.7±11.2	58.7±7.0	79.4±2.7
	MEAN±SEM	68.7± 8.4	63.5±6.6	79.3±1.8
NAIE05C 70-102	LIN LST	80.8± 9.9	48.0±3.2	66.3±2.9
	MEAN±SEM	79.8± 6.3	53.1±3.8	68.1±3.9
Grouped 4-102	LIN LST	85.2±13.0	68.0±6.2	81.0±1.1
	MEAN±SEM[a]	81.9± 8.8	68.5±3.3	81.4±1.4

[a]Standard error of the man (SEM) for this row based on deviation from regression line.

significantly lower for the HF-washed samples - results of paired "T" tests among the three sample treatment groups showed significant differences between both the HF-washed samples and the unetched samples ($p<0.005$) and the HF washed samples and the HF-etched samples ($p<0.005$). For the individual depths, the fully etched samples show a pattern consistent with decreasing dose through the brick as would be expected for penetrating gamma rays: 97 ± 4,

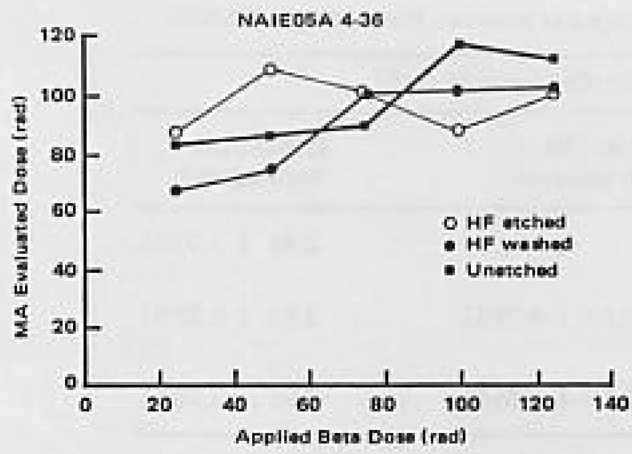

Figure 10. Ieno-cho wall sample NAIE05 multiple activation 4-36mm from exposed surface

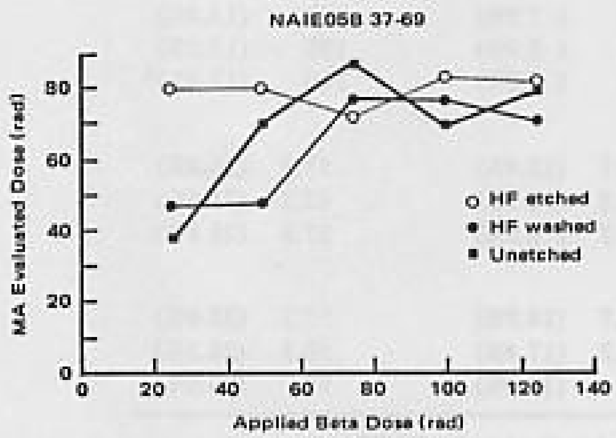

Figure 11. Ieno-cho wall sample NAIE05 multiple activation 37-69mm from exposed surface

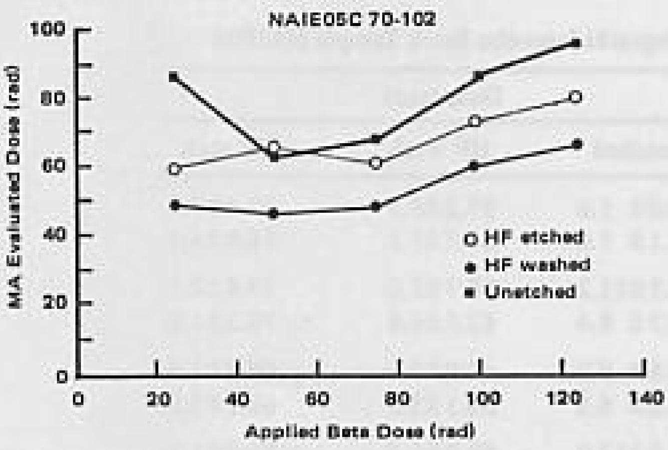

Figure 12. Ieno-cho wall sample NAIE05 multiple activation 70-102mm from exposed surface

79 ± 2, and 68 ± 4. These values are also consistent with the high temperature TL results reported by Huxtable[6] for the same brick and depths: 95 ± 10, 80 ± 9, and 73 ± 8; they are also consistent with the high temperature results reported by Bailiff[2] for similar depths of brick NAIE06: 95 ± 10, 85 ± 9, and 70 ± 9. Bailiff gives greater weight to results of the MAD analyses of those samples, however, which gave results of 117 ± 5, 84 ± 3, and 77 ± 3. His corresponding MA values were 103 ± 2, 72 ± 3, and 87 ± 2. All quoted uncertainties relate to precision of measurements only. Results of analyses of additional Ieno-cho wall bricks are shown in Figure 13.

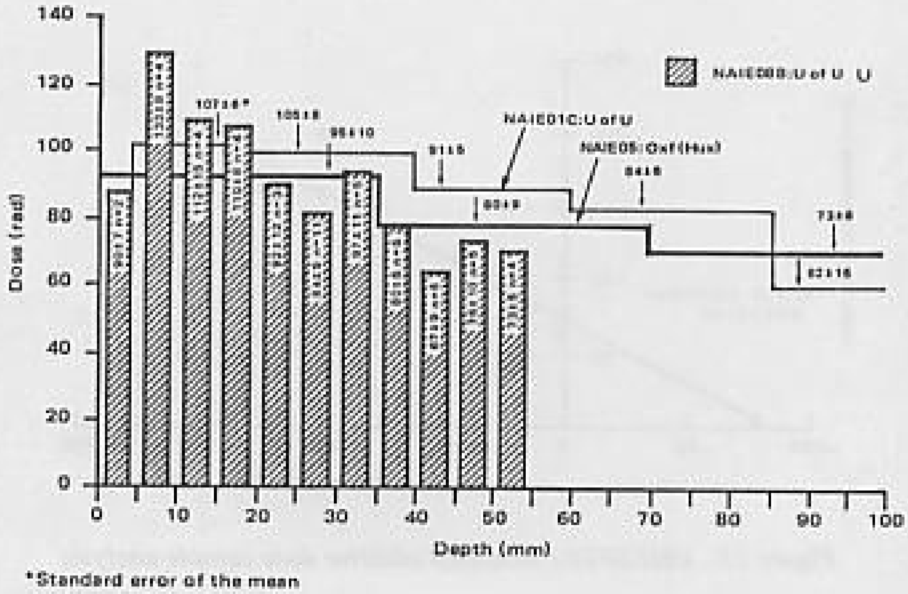

Figure 13. Results of analysis of additional Ieno-cho wall brick sample

Hiroshima Samples (UHFSFT Floor Tiles)

Two floor tiles removed recently from the roof of the Faculty of Science building of the University of Hiroshima (1433 m from the hypocenter) were cut in half at UU with a diamond masonry saw. One half of each tile was retained while the other halves were sent to Oxford (UHFSFT03) and Durham (UHFSFT02) Universities for analysis. Portions of the retained halves of the tiles were prepared for pre-dose TL analysis in this laboratory. The outer 3 mm of tile was removed with a water cooled masonry saw. The resulting portions (3 to 18 mm depth) were prepared using standard procedures. Pre-dose analyses included TAC, MA, and MAD.

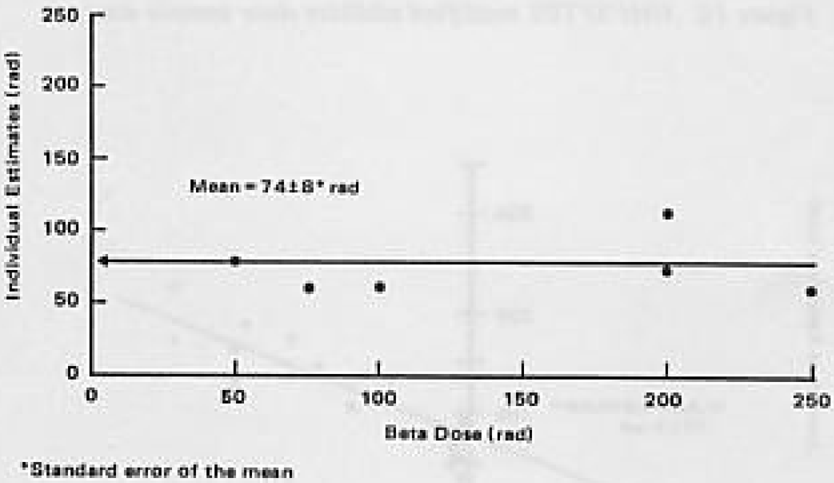

Figure 14. UHFSFT03 multiple activation sample analysis

Results. Results of individual analyses for MA and MAD runs are shown in Figures 14 to 17. Results, in summary, are (all doses in rad): UHFSFT02 MA mean = 78 ± 5, MAD mean 70 ± 9. UHFSFT03 MA mean 74 ± 8, MAD mean = 80 ± 13. Results of TL analyses of UHFSFT02 from Durham were 77 ± 6, 150 ± 15, and 80 ± 9 for high temperature, MA,

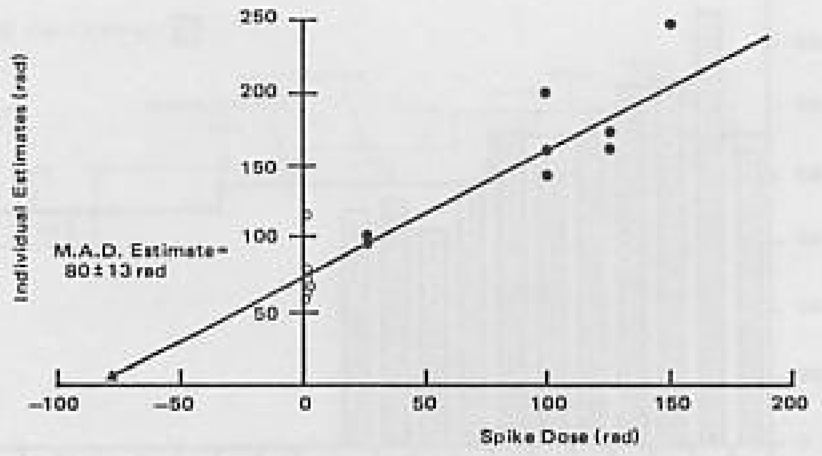

Figure 15. UHFSFT03 modified additive dose sample analysis

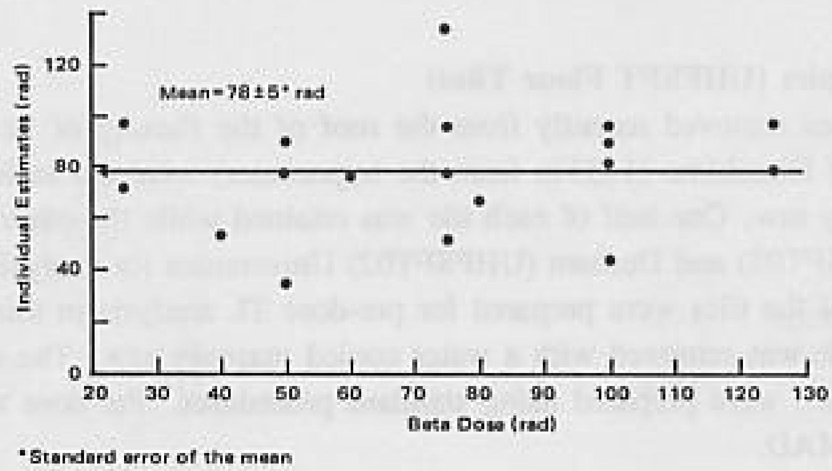

Figure 16. UHFSFT02 modified additive dose sample analysis

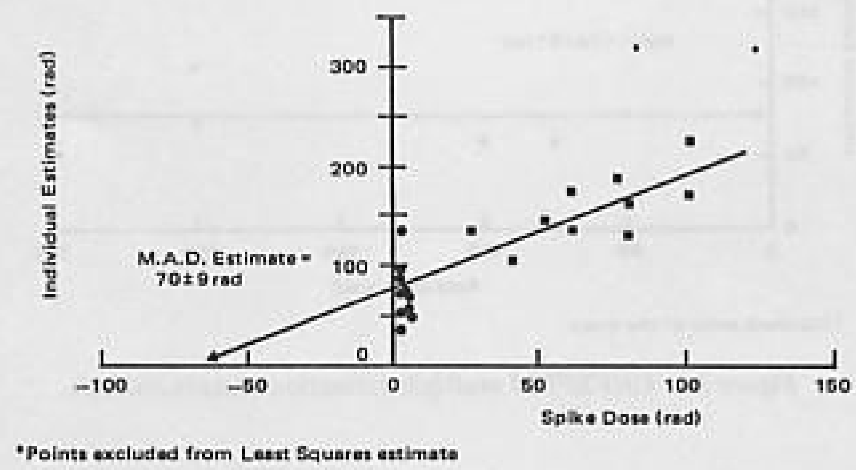

Figure 17. UHFST02 modified additive dose sample analysis

and MAD analyses, respectively. For UHFSFT03 sent to Oxford, Huxtable reported a dose 84 ± 10 using the high temperature technique. Stoneham reported doses of 87 ± 7 for MA, 83 ± 20 for additive dose at 595°C activation temperature, 46 ± 7 for additive dose using 615°C activation temperature, 82 ± 4 for high temperature analysis at 250°C using a 20% fading correction, and 87 ± 9 for 275°C high temperature analysis with no fading correction.

Hiroshima Samples (Railing Tiles)

Our previous report[5] described samples, preparation procedures, and preliminary results of analyses of seven ornamental tiles removed from the Faculty of Science building at Hiroshima University. Additional aliquots of many of these samples have been analyzed and the results are presented below. Because effects due to HF washing were seen in the Ieno-cho brick samples, the UHFS samples were examined for similar treatment effects. The results are presented in Table 6.

Table 6. Results for Railing Tiles from Hiroshima University

Code	Distance (m)	Non-HF-washed			HF washed		
		rad[a]	N	SEM	rad[b]	N	SEM
UNFS01	1426	73	10	5	58	15	3
UHFS02	1396	110	9	7	103	7	13
UHFS03	1389	106	9	3			
UHFS04	1451	83	5	4	60	8	3
UHFS05[c]	1430	14	3	1	16	3	4
UHFS06[c]	1455	25	3	1	22	5	2
UHFS07	1454	67	2		73[a]	2	

[a]Derived from the mean of the MA dose estimates.
[b]Derived from the curve fit as described below.
[c]Shielded tiles.

When evaluated dose is plotted versus applied calibrating dose for individual tiles (Figure 18), a net positive slope is found in the HF-washed samples (0.16 ± 0.22) relative to the non-HF treated sample (0.02 ± 0.10). This effect would normally be indicative of nonlinear filling of "R" centers; however, similar effects could be produced by competing TL signals from impurities produced during the HF treatment (I. K. Bailiff, personal communication). In the case of nonlinear filling of "R" centers, a correct estimate of dose can be obtained using a calibrating dose equivalent to the accrued dose. One method of arriving at this dose involves curve fitting and extrapolation to the "evaluated dose" axis at the point on the curve at which the calibrating dose is equivalent to the evaluated dose estimate. In one sample (UHFS02) the evaluated dose obtained with curve fitting was 103 ± 13 rad while the evaluated dose derived from the mean of the MA measurements was 88 ± 8 rad. The mean-derived estimate of 88 rad for the HF-washed crystals is clearly inconsistent with results for the non-HF treated crystals from the same tile: 113 ± 9 and 110 ± 7 rad for mean-derived and curve-fit estimates, respectively. Because of the uncertainties associated with HF-washed crystals, greatest confidence at this time should be placed in results from the non-HF treated samples.

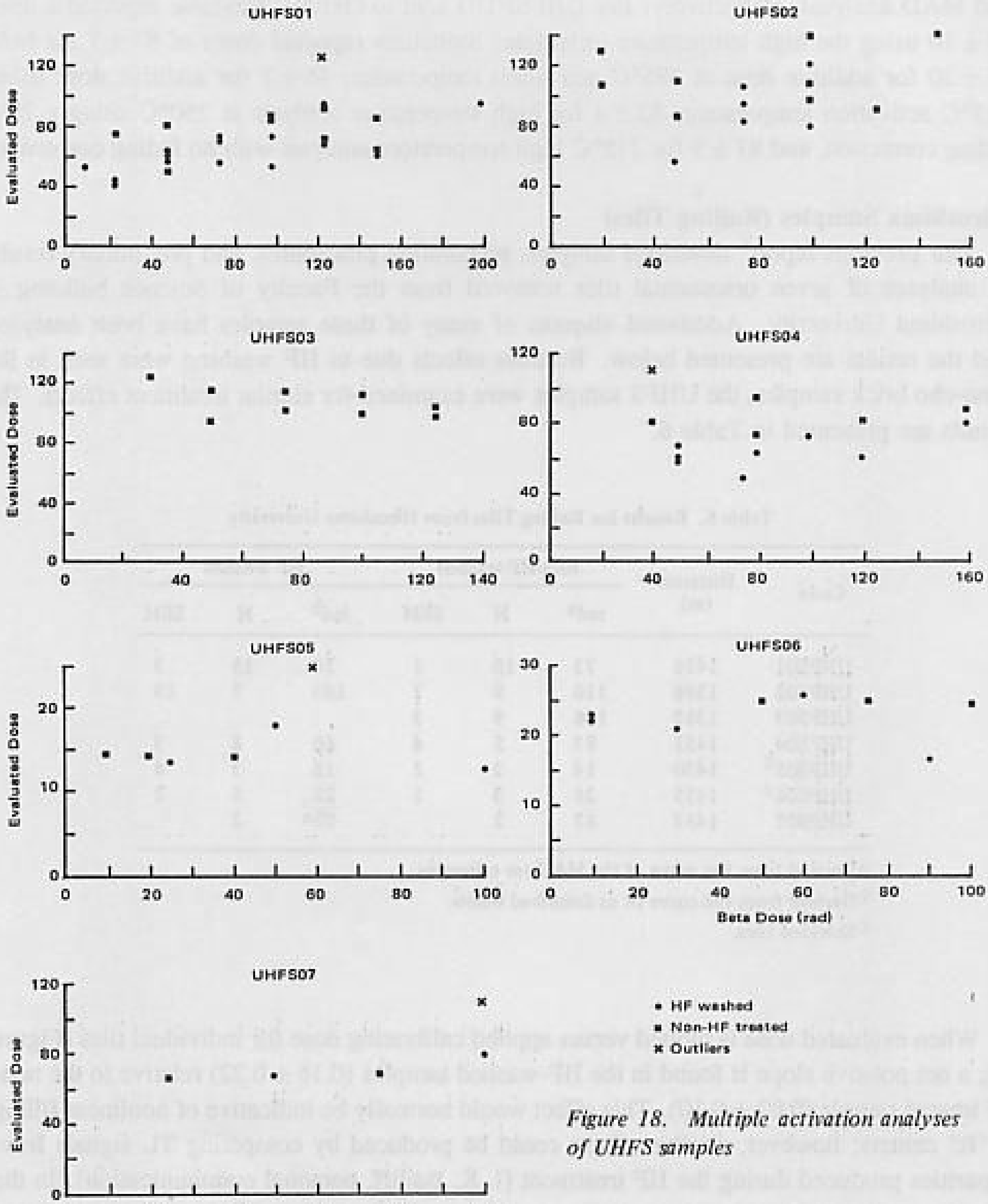

Figure 18. Multiple activation analyses of UHFS samples

No significant differences were found in a comparison between MAD estimates and MA estimates for the HF-treated samples (Figure 19). An ultraviolet reversal test on the samples indicated that the initial sensitivity of one sample (UHFS01) was elevated by approximately 25 %. This sample also differed greatly in internal composition from the other tiles, being composed of a concrete core surrounded by a clay coating. For these reasons it is suggested that sample UHFS01 be excluded from further analysis.

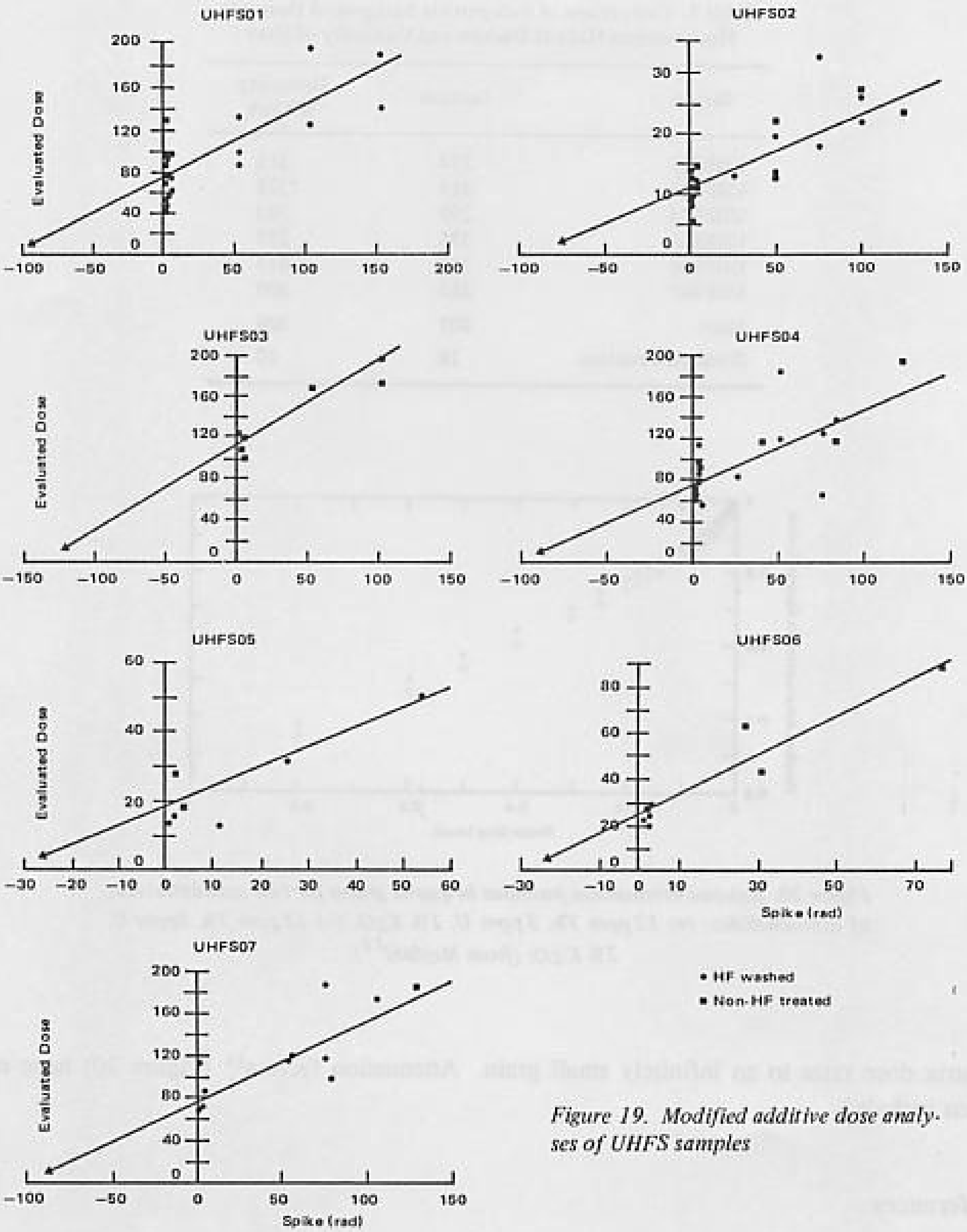

Figure 19. Modified additive dose analyses of UHFS samples

Beta-particle Background Dosimetry

Samples of UHFS tiles were crushed completely to a grain size of less than 106 μm. The samples were then analyzed at UU using beta-particle TL dosimetry units provided by Durham University[9,10] and calibrated using Durham sources at UU. Table 7 is a comparison of samples from railing tiles from the Faculty of Science building of Hiroshima University analyzed at Durham University versus those analyzed at Utah. Utah results refer to infinite-

Table 7. Comparison of Beta-particle Background Dose-rate Measurements Made at Durham and University of Utah

Sample	Durham	University of Utah
UHFS02	294	315
UHFS03	319	321
UHFS04	299	303
UHFS05	335	297
UHFS06	313	317
UHFS07	283	300
Mean	307	309
Standard deviation	19	10

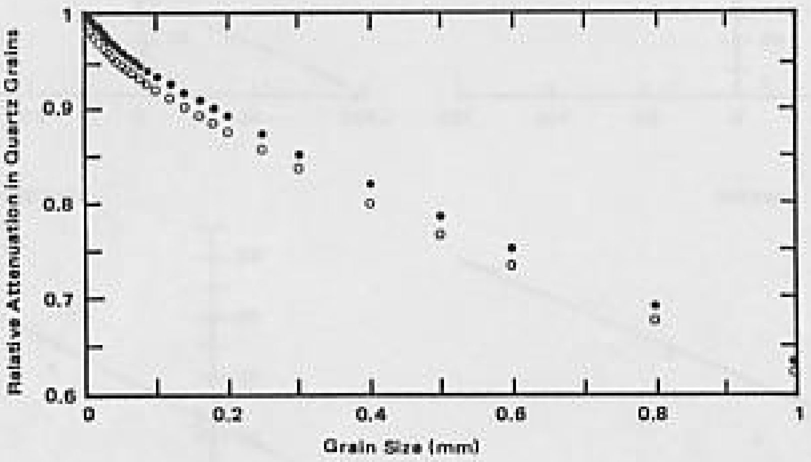

Figure 20. Relative attenuation fractions in quartz grains for two concentrations of radionuclides: (•) 12 ppm Th, 3 ppm U, 1% K_2O; (○) 12 ppm Th, 3ppm U, 2% K_2O; (from Mejdahl[11])

matrix dose rates to an infinitely small grain. Attenuation factors[11] (Figure 20) have not been included.

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Chapter 4 Appendix 6a

REPORT FROM THE ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE CONCERNING LINAC AND ^{60}Co IRRADIATIONS

Douglas Eagleson
Armed Forces Radiobiology Research Institute

The linear accelerator (LINAC) at the Armed Forces Radiobiology Research Institute (AFRRI) was used to irradiate samples of silicon and aluminum oxides for E. H. Haskell of the University of Utah. The samples were irradiated with bremsstrahlung of 6 MeV effective energy from 52 4-μs pulses (60 pulses per second) of 18.75 MeV electrons after the photons passed through a beam-flattening filter.

The oxides were in quartz capsules provided by the National Bureau of Standards (NBS). The capsules were placed inside a box-shaped glass (density 2.5 g cm^{-3}) container 32 × 32 × 4 cm. Photons penetrated the 4 cm dimension through walls 0.56 cm thick. The container was on a wooden table 233 cm from the exit port of the LINAC.

Dosimetry was done according to the AAPM Task Group 21 Protocol.[1] Six lithium fluoroid (LiF) ribbons (TLD 100 batch T-1776 S(1)5) were placed on top of the capsules during irradiation as monitors. The LiF was calibrated against an ionization chamber: in an unattenuated beam 0.0095 Gy to the LiF per LINAC pulse and 0.0108 Gy to silicon dioxide.

Precision (standard deviation) was 3%.

Two capsules were irradiated. The LiF monitors differed by 1%, averaging 0.465 Gy. The dose to silicon dioxide was thence, $0.465 \times 0.0108/0.0095 = 0.529$ Gy with a precision of 3%.

^{60}Co Irradiations

The AFRRI ^{60}Co facility was used to irradiate two more samples in NBS capsules. The facility consist of 107 separate ^{60}Co elements stored under approximately 5 m of water. The elements are raised above the water to make the irradiation; 3.7% of the dose to the capsules was received while the elements were rising or falling.

The capsules were placed on a foam spacer, on a plastic box, on a wooden table; the capsules were 367 cm from the ^{60}Co.

Three LiF ribbons (same batch as above) inside 4-mm thick A-150 plastic buildup caps were placed 2 cm from the NBS capsule as monitors. The AAPM protocol was used.[1] The LiF was calibrated against an ionization chamber: in an unattenuated beam 0.097 Gy per minute to LiF and 0.104 Gy per minute to silicon dioxide. Precision (standard deviation) was 3%.

Two capsules were irradiated. The LiF monitors differed by 4%, averaging 0.465 Gy. The dose to silicon dioxide was thence, $0.465 \times 0.104/0.097 = 0.500$ Gy with a precision of 3%.

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Chapter 4 Appendix 6b

REPORT ON METHODOLOGY OF CALIBRATION AND IRRADIATION OF SAMPLES WITH THE UDM ^{137}Cs BEAM IRRADIATOR AT THE UNIVERSITY OF UTAH

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The physical aspects of the University of Utah ^{137}Cs irradiation facility is shown in Figure 1. Chambers or samples are held in place by a stand that may be raised or lowered on a table that may be raised or lowered and moved to various distances from the irradiator.

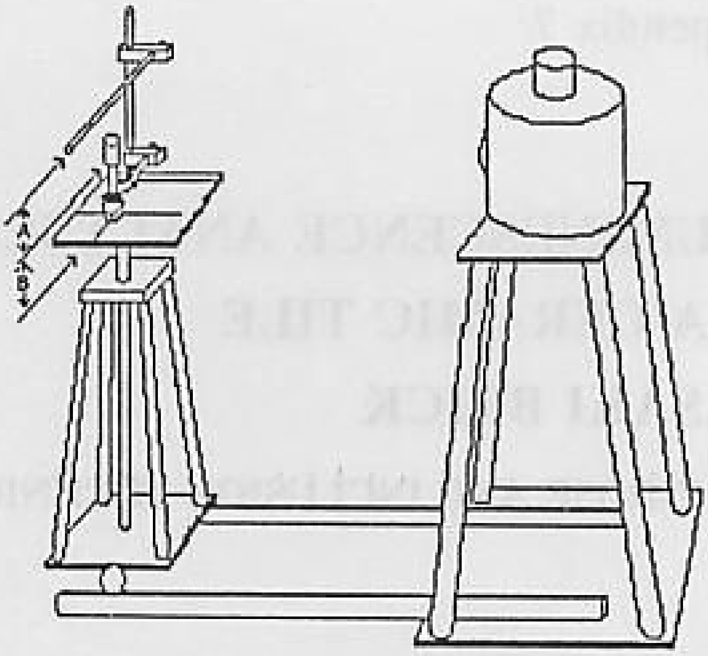

Figure 1. The ^{137}Cs irradiator at the University of Utah

The irradiator has three exposure modes that depend on the positions of an attenuator and an aperature plug covering the source. The thermoluminescence dosimetry samples for the reassessment program were exposed with both the attenuator and aperature plug removed. They were exposed at approximately 100 cm, where the exposure rate was approximately 20 R/h (changing as the ^{137}Cs decays). The room is large enough that the direct beam strikes only the chamber or sample, the table and stand, and the back wall. The wall is about 6 m from the source. No measurements have been made of the scatter from the table; the scatter is assumed to be small and constant. An investigation of the scatter from the support holding the sample showed no statistically significant differences for a wide range of positions of the support.

Exposures in the beam were determined with Victoreen Model 633 (2.5 R) and 70-5 (25 R) ionization chambers and a Model 570 electrometer, all with serial number 611. These devices were calibrated at the University of Wisconsin,[1,2] where there is a dosimetry calibration laboratory accredited by the American Association of Physicists in Medicine. Accreditation requires that the calibrations be directly traceable to primary standards maintained at the National Bureau of Standards.

References

1. University of Wisconsin, 1984. *Report of Calibration for Electrometer*. Madison, WI: University of Wisconsin, Department of Medical Physics, report EM058.
2. University of Wisconsin, 1984. *Report of Calibration for Ionization Chamber*. Madison, WI: University of Wisconsin, Department of Medical Physics, report ION082.