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Test Cell C Shielding Study
Kiwi B4D-202

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ABSTRACT

Gamma and neutron doses at 71 and 19 stations, respectively, in the Test Cell C complex at the Nuclear Rocket Development Station were measured during the full-power run of the Kiwi B4D-202 reactor to determine shielding effectiveness of the test cell structures.

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CONTENTS

	Page
ABSTRACT	3
INTRODUCTION	7
DOSIMETRIC METHODS	7
RESULTS AND CONCLUSIONS.	9

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INTRODUCTION

Documentation of the shielding effectiveness of permanent structures in the Test Cell C complex of the Nuclear Rocket Development Station, Jackass Flats, Nevada, was made on Experimental Plan 4 (EP-4) of the Kiwi B4D-202 Reactor (held on May 13, 1964) by the Field Studies Group (H-8) of the Health Division of the Los Alamos Scientific Laboratory. Some of the results of the study can be extrapolated to determine the doses at various locations during future reactor tests and to assess radiation hazards in case of an inadvertent criticality event.

In addition to the above measurements, Group H-8 also made integral gamma and integral neutron measurements, gamma dose rate measurements, and radioactive effluent measurements on the Kiwi B4D-202 tests. The results are reported elsewhere.¹⁻³

DOSIMETRIC METHODS

Integral gamma measurements for this study were made with the glass dosimeter system used on the Test Cell A shielding study⁴ and on the Kiwi series of reactors. Basically, the system consists of silver phosphate activated glass rods having a range of 2×10^1 to 5×10^4 rads and cobalt borosilicate glass plates having a range of 10^4 to 5×10^6 rads. The rods and plates were placed in ^6Li impregnated lead cans to minimize the effects of thermal neutrons and to lessen the effect of low-energy

gamma rays on the glass. Doses to the rods were evaluated by a specially adapted Turner 970 Fluorometer. Doses to the cobalt glass were measured with a Bausch and Lomb Spectronic 20 Colorimeter Spectrophotometer. Readings from these instruments were converted to gamma dose values by means of ^{60}Co calibration curves. A more detailed description of the above system is given in earlier reports.^{1, 5, 6}

To supplement the above system in the low-dose region, DuPont 544 film packets were used. These packets contained a sensitive film, type 555, which measured doses ranging from 0.03 to 10 rads and an insensitive type film, type 834, which measured doses from 10 to 10^3 rads. A 40-mil lead strip surrounded the films so that gamma exposures could be distinguished in the presence of beta radiation. Film densities behind the lead strip were measured with an Ansco Densitometer and converted to gamma doses from ^{60}Co curves.

Two gold foils, one bare and one encased in cadmium, were placed at selected stations. The differences in their activities gave a measure of the thermal neutron fluence. The $^{32}\text{S}(n, p)^{32}\text{P}$ reaction has a threshold of 2.5 MeV. The beta activity of the ^{32}P is a measure of the neutron fluence greater than 2.5 MeV. This system is discussed in more detail in other reports.^{1, 5, 7}

The combination gamma-neutron dosimeter is shown in Figure 1. Several capsules containing thermoluminescent powder were placed in these holders for research purposes in thermoluminescent dosimetry. These holders were usually taped in position. A "gamma only" packet (film packet plus glass dosimeters in a LiPb can) is shown in Figure 2, and a typical mounting (using tape) is shown in Figure 3.

The neutron dosimeters were placed at the first 19 stations and the gamma dosimeters at all 71 stations. All stations and their approximate distance from the reactor are listed in Table I. The actual distribution

of the dosimeters is shown in the Test Cell C area maps (Figures 4 through 6). The dosimeter placement was accomplished on May 1 and 6 in preparation for EP-4 held on May 13, 1964. Thus, the dosimeters were irradiated slightly ($\sim 0.4\%$ of the integral) on the low-power power-profile run (EP-3) held on May 8, 1964.

RESULTS AND CONCLUSIONS

The resultant integral neutron fluxes and shielding effects caused by the structures are listed in Table II. The integral gamma doses and shielding effects are given in Table III. The shielding effect is the ratio of the integral dose at the station mentioned to the integral dose at an equidistant unshielded location. The unshielded stations were located on the H-8 freeline composed of a trolley line ranging from 60 to 840 ft from the core center at a bearing of 292° and a line of goal posts from 600 to 3000 ft at a bearing of 20° . The gamma dose versus distance curve for these stations is given in Figure 7, and the integral neutron flux versus distance curve for the same stations is given in Figure 8.

Since the shielded station dosimeters were not removed until the evening of and the morning after the full-power run, their integral doses include in addition to the dose due to the full-power run, the dose due to decay of the reactor fission product inventory for about 6 to 24 hr, and the dose due to the decay of neutron induced activation of the test cell area.

The trolley line stations were remotely removed to 840 ft 10 to 15 min after the run and were recovered (as were the goal posts) within several hours after the run. The integral of the free air gamma dose rate curve at 60 ft shown in Figure 9² indicates that about 95% of the total free air dose was received during the run plus the first 10 min of decay. Even

though the decay in the shielded area locations is different from free air decay,⁸ the integrals of the dose rate curves from Victoreen Remote Area Monitoring Stations in shielded locations indicate that less than 10% of the total shielded area location integral is received after 10 min post scram.⁹ Thus, the shielding effect column in Table III is not significantly affected by different decays and recovery times between free air and shielded station locations.

The value of the shielding effect ranges from 8.83×10^{-6} to 1.1 for thermal neutrons, from 6.61×10^{-6} to 1.39×10^{-1} for fast neutrons (> 2.5 MeV), and from 2.06×10^{-7} to 1.27 for gamma rays. There is a slight enhancement amounting to an additional 10% of the thermal neutron fluence at station 10 (J-6 operators' trailer). Apparently, the moderation of fast neutrons adds to the fluence more than is lost due to attenuation of thermal neutrons. There is also a 27% enhancement of the gamma dose at station 67, which was placed about 5 ft high on the fence to the east of the reactor and in direct line of sight with the reactor. Several factors enter in to make this reading higher than the trolley line dose at an equal distance. At 400 ft from the reactor, the trolley line is about 30 to 35 ft over a gully; thus station 67 was exposed to more ground scatter and activation. It was among the last stations to be recovered and thus saw about 5% more dose due to decay. Also, with an 8 to 10% error in reading the glass rods, it is believed that the apparent error in the dose at station 67 is within the limits of experimental error. On the map station 69 appears to be in direct line of sight with the reactor. Actually, it is in a shielded location thus giving the shielding effect of 0.486.

It can be seen that locations completely surrounded by shielding material receive less dose than those only partially shielded. For

example, stations 57 and 60 are the same distance from the reactor and nearly in the same place but, station 60 (outside) received a gamma dose 1.8 times greater than station 57 (inside).

Any use of the data presented in this report must take into account future modifications in the test cell.

Fig. 1. Gamma-neutron dosimeter holder containing (left to right) cadmium covered gold foil, sulphur pellet, film packet, loaded glass dosimeter can, four thermoluminescent capsules, and a bare gold foil.

Fig. 2. Plastic clad DuPont 544 film packet and $^5\text{LiPb}$ can containing glass dosimeters.

Fig. 3. Typical placement of gamma dosimeters.

Fig. 4. Ground floor and basement shielded station locations at Test Cell C.

Fig. 5. Shielded station locations in south half of Test Cell C.

Fig. 6. Shielded station locations in north half of Test Cell C.

Fig. 7. Integral gamma dose versus distance at freeline stations. Kiwi B4D-202, EP-4.

Fig. 8. Integral neutron flux versus distance at freeline stations, Kiwi B4D-202, EP-4.

Fig. 9. Gamma dose rate at the 60 foot station (unshielded).

TABLE I. DETECTOR PLACEMENT FOR TEST CELL C SHIELD STUDY

Station	Approx. Distance From Reactor (ft)	Location
1	80	South side of test cell extension wall, 3' above ground and 40' from east end
2	100	South side of test cell extension wall, 3' above ground and 20' from east end
3	80	Underside of overhang roof at gas storage area
4	80	Over No. 3 station, 3' 8" above overhang roof
5	30	Inside Detector Room on west wall 5' 4" above floor and 3' from south wall
6	100	On pipe on top of test cell, 8' 6" above roof and 8' 3" from west end of roof
7	165	On pipe 10' above LH ₂ Pump Room roof
8	325	On pipe 5' 6" above Compressor Room roof
9	405	On southeast side of ground water tank 4' 6" above ground
10	470	Outside north wall of J-6 Operator's Trailer
11	30	Inside Hookup Room on north wall 4' 4" above floor and 2' 6" from west wall
12	25	Inside Radiation Effects Room on north wall 6' above floor and 4' 8" from west wall
13	30	Inside MER ^(a) on north wall 6' above floor and 2' 6" from west wall
14	60	Inside MER on east wall 4' 5" above floor and 5' 3" from south corner
15	55	Inside FCR ^(b) on north wall 9' 4" above floor and 16' 9" from east wall
16	310	Inside Compressor Room at center of ceiling
17	35	On Penthouse roof south guard rail, 3' 9" above Penthouse roof and 13' 7" from east end of roof
18	95	South end of test cell 13' 2" above roof and 28' 2" from west side
19	55	In middle of ELR ^(c) on rack 76
20	60	South side of shield wall 3' above ground and 62' from east end of wall
21	115	South side of shield wall 3' above ground and 1' from east end of wall
22	105	Middle of gas storage area on base of concrete pedestal
23	20	South of shield wall 4' 5" above Penthouse and 10' 6" from east end of roof
24	25	Outside of test cell west wall 4' 8" above ground and 3' 6" from shield wall
25	40	In stair well of west entrance to MER 5' 6" from floor and 2' from north wall
26	95	Outside south wall of test cell by entrance to FCR and 7' 4" above ground
27	125	Inside north wall of CEL ^(d) , 5' 6" above floor and 8' from west wall
28	165	Inside south wall of CEL, 5' 6" above floor and 14' from west wall
29	200	Inside south wall of LH ₂ Pump Room, 6' above floor and 7' 9" from west wall
30	180	Inside north wall of Electric Drive Building, 6' above floor and 30' 9" from east wall

TABLE I. (continued)

Station	Approx. Distance From Reactor (ft)	Location
31	235	Inside south wall of Electric Drive Building, 6' above floor and 26' 8" from east wall
32	240	Outside south wall of Electric Drive Building, 6' above ground and 14' from west wall
33	205	Between Dewars, 3' above ground
34	200	Between Dewars, 3' above ground and 10' 4" west of midline of Dewars
35	170	Inside north wall of LH ₂ Pump Room, 5' 9" above floor and 6' 3" from east wall
36	35	Inside east wall of Detector Room, 5' 7" above floor and 2' 3" from south wall
37	70	Inside west wall of FCR, 8' 9" above floor and 25' from north wall
38	700	Inside north camera bunker in middle of Camera Room
39	850	Inside south camera bunker in middle of Camera Room
40	605	At Victoreen station near main access gate to test cell area
41	295	Inside north wall of Compressor Room, 5' above floor and 23' from west wall
42	315	Inside FSC ^(e) on operator's console, 2' 4" above floor
43	320	In middle of Compressor Room, 5' 5" from floor, 21' 6" from east wall and 7' 9" from south wall
44	100	South of shield wall, 3' south of wall, 4' from east end of wall and 3' above ground
45	115	Southwest of reactor, 3' above ground
46	80	Outside east wall of test cell at middle of wall
47	210	Southwest from reactor, 12' west of Motor Drive Building and 3' above ground
48	40	Above test cell roof, 6' 6" behind Penthouse and 3' above roof
49	55	In middle of FCR, 6' above floor, 18' from west wall and 31' from south wall
50	100	Inside north wall of FCR, 5' 5" above floor and 1' from south wall
51	95	Inside west wall of HPR ^(f) , 6' 8" above floor and 7' 8" from south wall
52	60	In middle of HPR, 5' 3" above floor, 8' 8" from west wall and 30' 8" from south wall
53	45	Inside north wall of HPR, 5' 9" above floor and 9' 8" from west wall
54	105	Inside south wall of MER, 5' 7" above floor
55	105	Inside south wall of MER, 5' 4" above floor and 5' 3" from east wall
56	30	Inside north wall of ELR, 6' above floor and 13' from east wall
57	330	Inside south wall of FSC, 5' 6" above floor and 21' from west wall
58	300	Inside north wall of FSC, 5' 5" above floor and 7' 9" from west wall

TABLE I. (continued)

Station	Approx. Distance From Reactor (ft)	Location
59	305	Inside north wall of FSC, 5' 2" above floor and 8' from east wall
60	330	Outside south wall of FSC, 5' 6" above ground and 39' from east corner
61	345	Outside south wall of Electric Bench Lab., 5' 4" above ground and 9' east of west corner
62	435	Outside south wall of Cryogenic Bench Lab., 5' 4" above ground and 12' from west corner
63	460	Outside north wall of test cell Manager's Trailer
64	475	Outside north wall of Restroom Trailer
65	620	On area fence at southeast corner
66	445	On area fence on east side
67	400	On area fence at north corner
68	365	On area fence at personnel gate north of reactor
69	265	On area fence west of reactor
70	250	On area fence by west personnel gate
71	625	On area fence 6' east of main entrance

- (a) MER = Mechanical Equipment Room
 (b) FCR = Flow Control Room
 (c) ELR = Electronics Room
 (d) CEL = Cryogenics Evaluation Laboratory
 (e) FSC = Fill Station Control
 (f) HPR = High Pressure Room

TABLE II. INTEGRAL NEUTRON FLUX AND SHIELDING EFFECTS

Station	Approx. Distance From Reactor	Fast Neutrons > 2.5 MeV		Thermal Neutrons ~0.3 eV		Cd ^(b) Ratio
		(n/cm ²)	Shielding ^(a) Effect	(n/cm ²)	Shielding ^(a) Effect	
1	80	6.99 x 10 ⁹	8.36 x 10 ⁻³	3.92 x 10 ¹²	1.75 x 10 ⁻¹	4.12
2	100	7.81 x 10 ⁹	1.48 x 10 ⁻²	4.05 x 10 ¹²	2.92 x 10 ⁻¹	4.16
3	80	1.12 x 10 ⁹	1.34 x 10 ⁻³	1.25 x 10 ¹²	5.58 x 10 ⁻²	3.57
4	80	2.76 x 10 ¹⁰	3.30 x 10 ⁻²	6.32 x 10 ¹²	2.82 x 10 ⁻¹	3.53
5	30	1.49 x 10 ⁸	2.23 x 10 ⁻⁵	9.58 x 10 ¹⁰	7.40 x 10 ⁻⁴	8.36
6	100	2.65 x 10 ¹⁰	5.36 x 10 ⁻²	6.81 x 10 ¹²	4.87 x 10 ⁻¹	3.61
7	165	1.16 x 10 ¹⁰	7.04 x 10 ⁻²	2.31 x 10 ¹²	5.44 x 10 ⁻¹	3.02
8	325	4.18 x 10 ⁹	1.27 x 10 ⁻¹	7.23 x 10 ¹¹	9.45 x 10 ⁻¹	3.01
9	405	4.75 x 10 ⁸	2.45 x 10 ⁻²	2.69 x 10 ¹¹	6.74 x 10 ⁻¹	3.85
10	470	1.88 x 10 ⁹	1.39 x 10 ⁻¹	2.85 x 10 ¹¹	1.10 x 10 ⁰	3.26
11	30	1.30 x 10 ⁸	1.92 x 10 ⁻⁵	4.95 x 10 ¹⁰	3.82 x 10 ⁻⁴	6.78
12	25	1.24 x 10 ⁸	1.31 x 10 ⁻⁵	6.46 x 10 ⁹	3.66 x 10 ⁻⁵	7.07
13	30	1.04 x 10 ⁸	1.55 x 10 ⁻⁵	9.18 x 10 ⁹	7.09 x 10 ⁻⁵	11.31
14	60	4.67 x 10 ⁷	2.65 x 10 ⁻⁵	1.37 x 10 ¹⁰	3.27 x 10 ⁻⁴	5.42
15	55	2.81 x 10 ⁷	1.45 x 10 ⁻⁵	3.69 x 10 ¹⁰	7.85 x 10 ⁻⁵	5.03
16	310	2.34 x 10 ⁸	6.22 x 10 ⁻³	1.28 x 10 ¹¹	1.49 x 10 ⁻¹	4.89
17	35	8.01 x 10 ¹⁰	6.61 x 10 ⁻⁶	1.58 x 10 ¹³	9.57 x 10 ⁻²	3.89
18	95	2.68 x 10 ¹⁰	4.75 x 10 ⁻²	6.66 x 10 ¹²	4.35 x 10 ⁻¹	3.59
19	55	7.05 x 10 ⁷	3.52 x 10 ⁻⁵	4.16 x 10 ⁸	8.83 x 10 ⁻⁶	9.79

(a) Shielding effect is integral flux obtained at shielded station divided by integral flux at equidistant unshielded location.

(b) Cadmium ratio is activity of cadmium encased gold foil divided by activity of bare gold foil.

TABLE III. GAMMA DOSES AND SHIELDING FACTORS

Station	Approx. Distance From Reactor (ft)	Gamma Dose (rad)	Shielding ^(a) Effect
1	80	3.05×10^3	5.89×10^{-2}
2	100	3.29×10^3	1.03×10^{-1}
3	80	1.65×10^3	3.18×10^{-2}
4	80	5.35×10^2	1.03×10^{-1}
5	30	2.65×10^2	6.82×10^{-4}
6	100	6.60×10^3	2.08×10^{-1}
7	165	2.62×10^2	2.32×10^{-1}
8	325	8.40×10^2	3.40×10^{-1}
9	405	3.42×10^2	2.33×10^{-1}
10	470	2.98×10^2	2.84×10^{-1}
11	30	2.23×10^2	5.73×10^{-4}
12	25	1.39×10^1 (b)	2.68×10^{-5}
13	30	1.66×10^1 (b)	4.27×10^{-5}
14	60	4.15×10^1 (b)	4.25×10^{-4}
15	55	1.01×10^2	8.58×10^{-4}
16	310	1.90×10^2	6.71×10^{-2}
17	35	1.12×10^4	3.81×10^{-2}
18	95	5.57×10^3	1.58×10^{-1}
19	55	1.22×10^3 (b)	1.04×10^{-5}
20	60	2.36×10^3	2.42×10^{-2}
21	115	3.66×10^3	1.56×10^{-1}
22	105	6.83×10^2	2.42×10^{-2}
23	20	3.80×10^4	5.57×10^{-2}
24	25	4.72×10^4	9.11×10^{-2}
25	40	2.69×10^2	1.15×10^{-3}
26	95	2.32×10^3	6.57×10^{-2}
27	125	3.72×10^3	1.86×10^{-1}
28	165	2.63×10^3	2.30×10^{-1}
29	200	1.15×10^3	1.53×10^{-1}
30	180	2.22×10^3	2.36×10^{-1}
31	235	1.33×10^3	2.51×10^{-1}
32	240	1.23×10^3	2.44×10^{-1}
33	205	2.92×10^3	4.07×10^{-1}
34	200	1.25×10^3	1.65×10^{-1}
35	170	1.07×10^3	9.99×10^{-2}
36	35	6.67×10^2	2.27×10^{-3}
37	70	3.25×10^2	4.60×10^{-3}
38	700	5.15×10^{-1} (b)	1.29×10^{-3}
39	850	2.75×10^{-1} (b)	1.17×10^{-3}
40	605	1.66×10^2	2.93×10^{-1}

TABLE III. (Continued)

Station	Approx. Distance From Reactor (ft)	Gamma Dose (rad)	Shielding (a) Effect
41	295	1.99×10^2	6.26×10^{-2}
42	315	6.80×10^1	2.51×10^{-2}
43	320	2.36×10^2	9.14×10^{-2}
44	100	1.01×10^4	3.18×10^{-1}
45	115	1.45×10^4	6.15×10^{-1}
46	80	1.52×10^3	2.93×10^{-2}
47	210	3.96×10^3	5.79×10^{-1}
48	40	1.36×10^4	6.11×10^{-2}
49	55	2.34×10^2	1.99×10^{-3}
50	100	4.44×10^2	1.40×10^{-2}
51	95	2.96×10^2	8.37×10^{-3}
52	60	2.38×10^2	2.40×10^{-3}
53	45	2.32×10^2	1.23×10^{-3}
54	105	3.00×10^1	1.06×10^{-3}
55	105	1.97×10^0	6.96×10^{-5}
56	30	8.00×10^{-2} (b)	2.06×10^{-7}
57	330	1.68×10^2	7.15×10^{-2}
58	300	1.05×10^2	3.43×10^{-2}
59	305	8.00×10^1	2.72×10^{-2}
60	330	3.03×10^2	1.29×10^{-1}
61	345	2.92×10^2	1.38×10^{-1}
62	435	2.71×10^2	2.09×10^{-1}
63	460	3.88×10^2	3.50×10^{-1}
64	475	3.05×10^2	2.98×10^{-1}
65	620	1.79×10^2	3.38×10^{-1}
66	445	4.05×10^2	3.44×10^{-1}
67	400	1.89×10^3	1.27×10^0
68	365	1.94×10^3	9.71×10^{-1}
69	265	2.00×10^3	4.86×10^{-1}
70	250	2.93×10^2	6.22×10^{-1}
71	625	1.77×10^2	3.33×10^{-1}

(a) Shielding effect is dose at shielded station divided by dose at equidistant unshielded location.

(b) Data obtained by film badges, all other listed data was obtained with Ag PO_3 glass rods.

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