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Appendix - XIII - Neutron Dosage from Sulphur and Phosphate Pills

A. Abstract - Sulphur and Phosphate Pills were used to measure the dosage of slow and fast neutrons as a function of distance. Analysis of the results on the phosphate pills show that dosages of slow neutrons of 1×10^{11} were obtained out to 600 yards from the burst. Considerable fast neutron intensity existed at the Skate but the dosage measurements are yet available.

B. The purpose of these measurements was to determine the relationship between neutron dosage and distance from the burst. The effect shielding by armor was also being investigated.

C. The pills, which were made of sulphur and calcium phosphate, were distributed on all target ships. After the test they were collected, and the induced radioactivity measured with a Geiger counter.

D. Calculations:

The calculation of the total number of neutrons per cm^2 were made according to the following formula: Total neutrons = KC

1. $K = \text{constant} = 3.1 \times 10^8$ for the $Ca_3(PO_4)_2$. No constant can be given for the sulphur until cross-section can be obtained from Los Alamos. The constant (for $Ca_3(PO_4)_2$) was derived from the following information:

a. The $Ca_3(PO_4)_2$ used weighed 1.00 grams which correspond to 3.88×10^{21} Atoms of P^{31}

b. The counter efficiency was 27.7%. This was determined by counting a standard uranium sample. The standard represented .006 curies of uranium.

c. The half-life of $P^{32} = 14.8$ days. The experimentally determined half-life of the $Ca_3(PO_4)_2$ pills was 15.6 days and for the sulphur pills was 14.5 days. (see Fig. 1)

d. Slow neutron capture cross-section of $P^{31} = 0.23$ barns. The cross-section of the sulphur will be obtained from Los Alamos.

e. Self absorption of the $Ca_3(PO_4)_2$ tablets was 2.6, i.e. when the tablet was powdered and spread quite thin the number of counts obtained was 2.6 times as great as before powdering. (see Fig 2) The same value was assumed for the sulphur pills, since P^{32} was the active component in both cases and the pills were the same size, mass, and shape.

2. $c =$ counts per minute calculated to the time of the Able day destination.

E. Limitations

These measurements are subject to a number of limitations and short comings which should be taken into consideration in their interpretation. Some of these factors are as follows:

1. The pills were not of proper shape and design. It was necessary to apply a self-absorption factor of 2.6 which is quite large and crudely determined. This factor may introduce considerable error. The pills also contained sugar and other substances which may have introduced impurities that could have contributed to neutron capture.

2. The determination of the efficiency of the counter may introduce errors. The radiations from the uranium standard are of the same energy as those from P^{32} .

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3. The capture cross-section of P is so low that all counts were low. The accuracy of a count is given by the formula:

$$\frac{Pe}{N_1 - N_2} = \frac{0.67 \sqrt{N_1 + N_2}}{N_1 - N_2}$$

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where Pe = probable error, N_2 = counts due to back ground of the counter and $N_1 - N_2$ = counts due to the sample. In making these measurements the pills containing little or no induced activity, were counted until $N_1 + N_2 = 200$. The back ground of the counters were approximately 20. On this basis a sample containing 10 counts/min. above back ground was counted to an accuracy of about 15% only (i.e. $Pe = 15\%$). In this report it is assumed that a pill having a count of 10 counts/min. above background has no significance. This places the lower limit of neutron detection at 3×10^9 neutrons/cm². The pills having 50 counts/min or more were counted with some what greater accuracy.

4. The descriptions of locations on board ships were frequently inadequate or not legible.

5. Very often the pills placed on exposed positions on board the ships were blown away by the blast. Most results represent the neutron dosage in positions having unknown amounts of shielding from the direct neutron burst.

F. 1. Experimental Data

All pills were counted that were recovered from ships located within 800 yards of the estimated point of detonation. Only token pills were counted from ships located from 800 to 1200 yards from the detonation. All results of slow neutron measurements are given in Table I. No attempt has been made to analyze the data other than to locate the maximum reading obtained aboard each ship on an overlay of the target array (Fig. 32). Decay curves, shown in Fig. 1, substantiate the fact that the activity being measured was due to P³².

2. The relationship of total slow neutrons to distance is shown in Table II. This table was compiled by taking the highest reading obtained on each ship as representing the neutron intensity at that point with no regard for shielding. The distance from that point to the estimated point of detonation was measured off from the map of the target array. These results show the following neutron dosages: at 400 yards, 1×10^{12} neutrons / cm², at 600 yards 1×10^{11} , 800 yards, 1×10^{10} and at 1000 yards about 3×10^9 .

3. The data in Table I may give considerable information on shielding effects when considered in connection with plans of the various ships. No attempt is made here to evaluate the data with respect to shielding because plans of the ships were not available. It is apparent however that there are rather great differences in measurements taken in various places on the ships. This is undoubtedly due largely to differences in distances from the point of detonation and in part to shielding. The variance in results on the Skate may be due in large measure to the fact that water is a good shielding material against neutrons.

4. The counts/min. obtained from the sulphur pills on the target ships are given in Table I. The calculation of the neutron intensities will have to wait until the capture cross-section for sulphur is obtained. However considerable fast neutron intensity was indicated on the Skate about 300 yards from the burst, and some fast neutrons may have penetrated as far as the Independence.

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| Sample No. | Ship | Location of Sample | $C_{23}(FO_2)_2$ neutrons/cm ² | Subbur counts/min. |
|------------|------------|-------------------------------------------------------|-------------------------------------------|--------------------|
| 1314 | Arkansas | A-40-M 5-30-4 | $< 3 \times 10^9$ | 0 |
| 1320 | Arkansas | A-50-M Frm. 4-39-4 | $< 3 \times 10^9$ | 0 |
| 1321 | Arkansas | A-35-M Frm. 5-29-4 | $< 3 \times 10^9$ | 0 |
| 1761 | Arkansas | Inside No. 6 turret 6" armor | 1.0×10^{10} | 1.8 |
| 1782 | Arkansas | 2nd Deck, Frm. 24, Stbd. | 1.67×10^{10} | 20.8 |
| 1783 | Arkansas | 2nd Deck, Frm. 128, Stbd. 2" armor | 5.5×10^{10} | 99.0 |
| 1784 | Arkansas | Amidships below armored deck | 6.18×10^9 | 6.5 |
| 1813 | Arkansas | Inside conning tower 12" armor | 5.0×10^9 | 0 |
| 1699 | Apogon | Bridge Forward Frm. 52 | 1.04×10^{10} | 4.9 |
| 1691 | Apogon | Conning Tower-amidships, Stbd. | 4.4×10^9 | 0 |
| 1692 | Apogon | Fwd. Torpedo Room | $< 3.0 \times 10^9$ | 0 |
| 1693 | Apogon | Fwd. Battery Compartment | $< 3.0 \times 10^9$ | 0 |
| 1694 | Apogon | Control Room | $< 3.0 \times 10^9$ | 0 |
| 1695 | Apogon | After Battery Compartment | $< 3.0 \times 10^9$ | 0 |
| 1696 | Apogon | Fwd. Engine Room | $< 3.0 \times 10^9$ | 0 |
| 1697 | Apogon | After Engine Room | $< 3.0 \times 10^9$ | 0 |
| 1698 | Apogon | Maneuvering Room | 3.41×10^9 | 0 |
| 1699 | Apogon | After Torpedo Room | 4.44×10^9 | 0 |
| 1751 | Apogon | Control Room, amidships, stbd. | $< 3.0 \times 10^9$ | 0 |
| 1752 | Apogon | Fwd. Battery Room, water- line, port | $< 3.0 \times 10^9$ | 0 |
| 1755 | Apogon | Bridge, amidships | $< 3.0 \times 10^9$ | 3.4 |
| 1756 | Apogon | Conning Tower, amidships, stbd. | $< 3.0 \times 10^9$ | 0 |
| 1759 | Apogon | After torpedo room, stbd., water line | $< 3.0 \times 10^9$ | 0 |
| 1760 | Apogon | Pump room, amidships, below control | $< 3.0 \times 10^9$ | 0 |
| 1614 | ARDC 13 | Frm. 55 stbd. | 1.14×10^{10} | 3.9 |
| 1615 | ARDC 13 | Frm. 8 stbd. | 3.5×10^9 | - |
| 755 | Banner | Signal Bridge, Frm. 92 port | $< 3.0 \times 10^9$ | 0 |
| 753 | Banner | Main deck, Frm. 39, port | $< 3.0 \times 10^9$ | 0 |
| 759 | Banner | Cabin deck, Frm. 73, stbd. | $< 3.0 \times 10^9$ | 0 |
| 838 | Brule | Unknown | $< 3.0 \times 10^9$ | 0 |
| 764 | Barrow | 40 mm barrel box | $< 3.0 \times 10^9$ | 0 |
| 770 | Barrow | Flying Bridge, phone box | $< 3.0 \times 10^9$ | 0 |
| 772 | Barrow | 20 mm, fwd, stbd. | $< 3.0 \times 10^9$ | 0 |
| 773 | Barrow | After stack on compass | $< 3.0 \times 10^9$ | 0 |
| 906 | Crittenden | Unknown (906-918 all in same but unknown location) | 3.06×10^{10} | 3.8 |
| 907 | Crittenden | ditto | 3.6×10^{10} | 6.3 |
| 908 | Crittenden | ditto | 3.1×10^{10} | 12.5 |
| 909 | Crittenden | ditto | 2.56×10^{10} | 0 |
| 910 | Crittenden | ditto | 2.91×10^{10} | 12.5 |
| 911 | Crittenden | ditto | 3.06×10^{10} | 23.4 |
| 912 | Crittenden | ditto | 3.22×10^{10} | 0 |
| 913 | Crittenden | ditto | 2.8×10^{10} | 18.7 |

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Table I (continued)

| | | | | |
|------|--------------|------------------------------------------------|-----------------------|------|
| 914 | Crittenden | ditto | 3.88×10^{10} | 10.3 |
| 915 | Crittenden | ditto | 2.44×10^{10} | 16.2 |
| 916 | Crittenden | ditto | 3.0×10^{10} | 13.5 |
| 917 | Crittenden | ditto | 2.42×10^{10} | 14.8 |
| 918 | Crittenden | ditto | 2.9×10^{10} | 2.7 |
| 930 | Dawson | Under sick bay Port #2 hatch | 7.6×10^9 | 1.0 |
| 931 | Dawson | After stack, compass platform | 9.5×10^9 | 16.2 |
| 933 | Dawson | Flying Bridge, fwd. stbd. | 1.8×10^{10} | 21.0 |
| 935 | Dawson | Compartment 10336, CPO berthing | 5.52×10^9 | 0 |
| 936 | Dawson | Fwd. Troop Compartment BH 27 | 6.95×10^9 | 17.0 |
| 938 | Dawson | A-104-L Frm. 47, port | 2.54×10^9 | 0 |
| 939 | Dawson | Mess Hall, Frm. 80 | 4.65×10^9 | 7.9 |
| 940 | Dawson | #2 Hold, BH - 108 | 2.42×10^9 | 0 |
| 941 | Dawson | After Troop Compartment BH - 135 | 3.0×10^9 | 0 |
| 942 | Dawson | Laundry Receiving Room, Frm. 157 | 4.8×10^9 | 2.2 |
| 1182 | Hughes | #7" Handling room 1st deck, Frm. 28, stbd. | 1.33×10^9 | 4.4 |
| 1187 | Hughes | Inside Mk 37 Director, near trainer's seat | 6.8×10^9 | 11.3 |
| 1191 | Hughes | Passageway outside CIC, O2 deck, frn. 66 | 7.7×10^9 | 7.9 |
| 1192 | Hughes | Wardroom, frn. 49 stbd, on fwd. bulkhead | 2.4×10^9 | 3.8 |
| 1289 | Independence | Flight Deck, fwd. port, frn. 10113 | 2.24×10^9 | 11.6 |
| 1290 | Independence | Flight deck, after port, frn. 52, stbd. | 5.98×10^9 | 20.6 |
| 1292 | ditto | Pilot House, O5 level, frn. 52, stbd | 6.5×10^{10} | 41.5 |
| 1294 | ditto | Crew's Head, B-202-4L, Frn. 75, port | 2.7×10^{10} | 40.5 |
| 1295 | ditto | Sick Bay Head A-312-2L, Frn. 50 Stbd. | 1.8×10^{10} | 9.0 |
| 1296 | ditto | Machine Shop, 3rd deck, Frn. 72 Stbd. | 1.21×10^{10} | 4.2 |
| 1298 | ditto | Fwd. Magazine, A-513-M, Frn. WRA 50 | 3.0×10^{10} | 0 |
| 1299 | ditto | ALPR 0208, FRM. 26, port bulkhead | 3.22×10^{10} | 19.5 |
| 1300 | ditto | Captains Cabin O2 deck, Frm. 44, stbd. | 3.35×10^{10} | 14.3 |
| 1302 | ditto | Fwd. Pilots Ready Room, C3 deck, frn. 44, port | 4.64×10^{10} | -- |
| 1303 | ditto | Crew's Galley 2nd deck, Frn. 94 | 1.94×10^{10} | 9.1 |
| 1304 | ditto | Storeroom C-412-A Frn. 127, port | 1.73×10^{10} | 11.3 |

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Table I (contin^d)

| | | | | |
|------|-------------------|-------------------------------------------------------------------|-----------------------|------|
| 1305 | ditto | Cold Storage Lunch C-307-IT Frn. 116 | 9.85×10^9 | 15.0 |
| 1308 | ditto | Admirals Cabin, Main Deck, Frn. 44, stbd. | 2.52×10^{10} | 31.7 |
| 1309 | ditto | Fwd. Engine Room Frn. 72 | 2.14×10^9 | 0 |
| 1310 | ditto | Ship's Tank B-902-W Fwd. Fire Room, Frn. 60, port | 2.48×10^9 | 3.6 |
| 1311 | ditto | Crew's Berthing Space C-703-L Frn. 124 | 3.85×10^{10} | 38.4 |
| 1347 | Nevada | Turret #1 Magazine, after bulkhead, center line compartment | 3.42×10^9 | 0 |
| 1350 | ditto | Pilot House, fwd. port, stbd. side | 2.0×10^{10} | 5.0 |
| 1351 | ditto | Pilot house, fwd. port, port side | 1.6×10^{10} | 12.1 |
| 1352 | ditto | #1 5"/33 Mount, inside on stbd. bulkhead | 1.85×10^9 | 7.7 |
| 1353 | ditto | #1 5"/33 Mount, inside on port bulkhead | 1.19×10^9 | 21.2 |
| 1356 | ditto | Crew's Head B-270-9L fwd. bulkhead | 9.9×10^9 | 0 |
| 1357 | ditto | Crew's Head B-270-9L after Bulkhead | 6.4×10^9 | 5.8 |
| 1358 | ditto | Sick Bay ward head, fwd. bulkhead | 2.42×10^9 | 7.2 |
| 1359 | ditto | Sick Bay ward head, after bulkhead | 1.3×10^{10} | 7.2 |
| 1725 | ditto | #1 turret overhead, amidships (center line) | 5.35×10^9 | 0 |
| 1737 | ditto | #4 turret overhead, amidships (center line) | 5.17×10^9 | 1.0 |
| 1738 | ditto | A-150-1L Stbd. bulkhead, fwd. | 1.05×10^9 | 1.0 |
| 1739 | ditto | Pilot House, amidships, on plotting table | 3.18×10^9 | 15.0 |
| 1743 | ditto | A-331-M, port bulkhead, fwd. Frn. 50 | 3.0×10^9 | 0 |
| 1747 | ditto | D-312-L, amidships, above armor, Frn. 128 | 1.62×10^{10} | 21.6 |
| 1478 | Nagato | 2nd Deck, Frn. 275, center line | 1.32×10^{10} | 6.5 |
| 1479 | ditto | Main Deck, Frn. 174, stbd. (outboard compartment) | 3.6×10^9 | 6.2 |
| 1480 | ditto | 3rd deck, Frn. 113, center line | 3.0×10^9 | 6.4 |
| 1838 | ditto | #4 turret, Frn. 57, out- side, aft.stbd.top. | 5.6×10^9 | 0 |
| 1766 | Pennsyl- vania | #3 Barbette, Frn. 48, fwd. outside | 3.0×10^9 | 0 |
| 1768 | ditto | Pilot House, Frn. 51 | 3.0×10^9 | 0 |
| 1421 | Pensacola | Sick Bay, Surgery | 4.64×10^9 | 2.9 |
| 1423 | ditto | Crew's Galley, stbd. | 4.69×10^9 | 0 |
| 1426 | ditto | After fire room, Port | 4.28×10^9 | 0 |
| 1429 | ditto | Crew's Galley, Port | 7.65×10^9 | 9.7 |

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Table I (continued)

pilot House Port

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|------|-----------|-------------------------------------------|-------------------------|-------|
| 1430 | Pensacola | Sick Bay, Surgery | 4.64 x 10 ⁹ | 20.8 |
| 1431 | ditto | CPO's Quarters | 2.17 x 10 ¹⁰ | 16.3 |
| 1432 | ditto | Fwd. Tire Room | 2.76 x 10 ⁹ | 3.5 |
| 1433 | ditto | Fwd. Engine Room | 1.01 x 10 ¹⁰ | 1.5 |
| 1434 | ditto | After radar station | 3.66 x 10 ⁹ | 14.8 |
| 1435 | ditto | #1 Turret | 2.76 x 10 ⁹ | 7.4 |
| 1436 | ditto | Mk 51 Director, aft (outside) | 2.37 x 10 ¹⁰ | 21.9 |
| 1437 | ditto | #4 turret ^{near} | 1.46 x 10 ¹⁰ | 11.3 |
| 1563 | Pardue | Bridge War Gyro Repeater | < 3.0 x 10 ⁹ | 0 |
| 1567 | ditto | Office, Frn. 45-47 | < 3.0 x 10 ⁹ | 0 |
| 1579 | ditto | Conning tower near steering stand | < 3.0 x 10 ⁹ | 0 |
| 1580 | ditto | Gun access trunk | < 3.0 x 10 ⁹ | 0 |
| 1586 | ditto | Motor Room, Frn. 100-102 | < 3.0 x 10 ⁹ | 0 |
| 1469 | Prinz | #1 Gun Chamber booth | < 3.0 x 10 ⁹ | 0 |
| 1470 | ditto | #1 turret powder handling room | < 3.0 x 10 ⁹ | 0 |
| 1472 | ditto | Stbd., outboard upward gun mount Frn. 139 | 3.44 x 10 ⁹ | 0 |
| 1473 | ditto | Navigation Bridge, Stbd. Frn. 169.5 | < 3.0 x 10 ⁹ | 0 |
| 1474 | ditto | Living comst. 3rd deck Frn. 111.1 Stbd. | < 3.0 x 10 ⁹ | 0 |
| 1476 | ditto | 3rd deck, Frn. 2.7 | < 3.0 x 10 ⁹ | 0 |
| 1477 | ditto | 3rd deck, port passage Frn. 38 | < 3.0 x 10 ⁹ | 0 |
| 1720 | ditto | Battle Station, Frn. 136 | < 3.0 x 10 ⁹ | 0 |
| 1728 | ditto | Fwd. main, switchboard room | < 3.0 x 10 ⁹ | 0 |
| 1130 | Rhind | Stbd. upper outboard 20mm. Mount Frn. 50 | 3.16 x 10 ⁹ | 6.8 |
| 1135 | ditto | Torpedo Shack, Frn. 130 | < 3.0 x 10 ⁹ | 0 |
| 1137 | ditto | Stbd. side of forecandle Frn. 20 | 4.6 x 10 ⁹ | 4.1 |
| 1146 | ditto | Bridge wheel, Frn. 60 | < 3.0 x 10 ⁹ | 0 |
| 1447 | ditto | A-401-A, Frn. 15, stbd. | < 3.0 x 10 ⁹ | 0 |
| 1465 | ditto | Main radio, Frn. 46 | < 3.0 x 10 ⁹ | 0 |
| 1466 | ditto | 40mm. clip shack, Nav. Bridge, Frn. 45 | < 3.0 x 10 ⁹ | 0 |
| 1604 | Skip Jack | Fuse box on Stbd. bulkhead Frn. 173 | < 3.0 x 10 ⁹ | 0 |
| 1605 | ditto | Stbd. bulkhead Frn. 63 | < 3.0 x 10 ⁹ | 0 |
| 1549 | Skate | After torpedo room, near wash basin | 2.19 x 10 ⁹ | 131.4 |
| 1550 | ditto | Motor room fwd. | 8.55 x 10 ⁹ | 1.4 |
| 1551 | ditto | Crew's wash room, over door | 2.75 x 10 ¹¹ | 74.0 |
| 1552 | ditto | After battery well | 2.09 x 10 ¹¹ | 45.3 |
| 1553 | ditto | Gun Trunk | 1.14 x 10 ¹² | 345.0 |
| 1554 | ditto | Pump room | 3.1 x 10 ¹⁰ | 12.7 |
| 1555 | ditto | Control room fwd. | 1.45 x 10 ¹¹ | 33.4 |
| 1556 | ditto | Control room, near trim manifold | 6.62 x 10 ¹⁰ | 50.1 |
| 1557 | ditto | Wardroom | 8.2 x 10 ¹⁰ | 12.7 |

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Table I (continued)

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|------|--------|---------------------------------------|-----------------------|------|
| 1558 | Skate | Wardroom | 7.65×10^{10} | 49.6 |
| 1559 | ditto | ditto | 1.0×10^{11} | 24.8 |
| 1560 | ditto | ditto | 8.0×10^{10} | 20.3 |
| 1561 | ditto | ditto | 6.8×10^{10} | 14.1 |
| 1166 | Stack | Stbd. upper, outboard 20mm. mount | $< 3.0 \times 10^9$ | 0 |
| 1168 | ditto | #1 5"/38 mount, port side of slide | $< 3.0 \times 10^9$ | 0 |
| 1119 | Talbot | Stbd. bridgwing Frn. 66 | $< 3.0 \times 10^9$ | 0 |
| 1126 | ditto | D-307-L, stbd, Frn. 156 | $< 3.0 \times 10^9$ | 0 |
| 1127 | ditto | D-210-L, overhead, stbd, Frn. 175 | $< 3.0 \times 10^9$ | 1.4 |
| 1129 | ditto | Wardroom bulkhead, Frn. 56 | $< 3.0 \times 10^9$ | 3.1 |

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Table II - App. XIII

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Total Neutrons/cm² in Relation to distance from Point of Detonation

| Ship | Distance | | No. Neutrons/cm ² Observed |
|-------------------------|----------|--------|------------------------------------------|
| | Yards | Meters | |
| Skate | 400 | 366 | 1.1 x 10 ¹² |
| Independence Aft. | 530 | 485 | 6.0 x 10 ¹¹ |
| Independence Forward | 600 | 545 | 2.2 x 10 ¹¹ |
| Arkansas | 610 | 555 | 5.5 x 10 ¹⁰ |
| Crittenden | 660 | 605 | 3.9 x 10 ¹⁰ |
| Nevada | 680 | 620 | 5.2 x 10 ¹⁰ |
| Pensacola | 710 | 650 | 2.4 x 10 ¹⁰ |
| Nagato | 780 | 713 | 1.3 x 10 ¹⁰ |
| ARDC-13 | 790 | 722 | 1.1 x 10 ¹⁰ |
| Hughes | 890 | 813 | 7.7 x 10 ⁹ |
| Dawson | 890 | 813 | 9.5 x 10 ⁹ |
| Apagon | 950 | 967 | 4.4 x 10 ⁹ |
| Rhind | 970 | 887 | 4.6 x 10 ⁹ |
| Brule | 990 | 905 | 2.6 x 10 ⁹ |

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