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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  $1 \times 10^{11}$  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 = 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  $3.88 \times 10^{21}$  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. Determination of the efficiency of the counter may introduce some error. Irradiations 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  $3 \times 10^9$  neutrons/cm<sup>2</sup>. 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,  $1 \times 10^{12}$  neutrons / cm<sup>2</sup>, at 600 yards  $1 \times 10^{11}$ , 800 yards,  $1 \times 10^{10}$  and at 1000 yards about  $3 \times 10^9$ .

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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UNCLASSIFIED  $C_{23}(F_{O_2})_2$   $\frac{neutrons/cm^2}{counts/min.}$

Sample No.	Ship	Location	$C_{23}(F_{O_2})_2$ neutrons/cm <sup>2</sup>	Sp. Rate 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	$1.0 \times 10^{10}$	1.8
1782	Arkansas	2nd Deck, Frm. 24, Stbd.	$1.67 \times 10^{10}$	20.8
1783	Arkansas	2nd Deck, Frm. 128, Stbd. 2" armor	$5.5 \times 10^{10}$	99.0
1784	Arkansas	Amidships below armored deck	$6.18 \times 10^9$	6.5
1813	Arkansas	Inside conning tower 12" armor	$5.0 \times 10^9$	0
1699	Apogon	Bridge Forward Frm. 52	$1.04 \times 10^{10}$	4.9
1691	Apogon	Conning Tower-amidships, Stbd.	$4.4 \times 10^9$	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	$3.41 \times 10^9$	0
1699	Apogon	After Torpedo Room	$4.44 \times 10^9$	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.	$1.14 \times 10^{10}$	3.9
1615	ARDC 13	Frm. 8 stbd.	$3.5 \times 10^9$	-
755	Banner	Signal Bridge, Frm. 92 port	$< 3.0 \times 10^9$	0
758	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)	$3.06 \times 10^{10}$	3.8
907	Crittenden	ditto	$3.6 \times 10^{10}$	6.3
908	Crittenden	ditto	$3.1 \times 10^{10}$	12.5
909	Crittenden	ditto	$2.56 \times 10^{10}$	0
910	Crittenden	ditto	$2.91 \times 10^{10}$	12.5
911	Crittenden	ditto	$3.06 \times 10^{10}$	23.4
912	Crittenden	ditto	$3.22 \times 10^{10}$	0
913	Crittenden	ditto	$2.8 \times 10^{10}$	18.7

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Table I (continued)

914	Crittenden	ditto	$3.88 \times 10^{10}$	10.3
915	Crittenden	ditto	$2.44 \times 10^{10}$	16.2
916	Crittenden	ditto	$3.0 \times 10^{10}$	13.5
917	Crittenden	ditto	$2.42 \times 10^{10}$	14.8
918	Crittenden	ditto	$2.9 \times 10^{10}$	2.7
930	Dawson	Under sick bay Port #2 hatch	$7.6 \times 10^9$	1.0
931	Dawson	After stack, compass platform	$9.5 \times 10^9$	16.2
933	Dawson	Flying Bridge, fwd. stbd.	$1.8 \times 10^{10}$	21.0
935	Dawson	Compartment 10336, CPO berthing	$5.52 \times 10^9$	0
936	Dawson	Fwd. Troop Compartment BH 27	$6.95 \times 10^9$	17.0
938	Dawson	A-104-L Frn. 47, port	$2.54 \times 10^9$	0
939	Dawson	Mess Hall, Frn. 80	$4.65 \times 10^9$	7.9
940	Dawson	#2 Hold, BH - 108	$2.42 \times 10^9$	0
941	Dawson	After Troop Compartment BH - 135	$3.0 \times 10^9$	0
942	Dawson	Laundry Receiving Room, Frn. 157	$4.8 \times 10^9$	2.2
1182	Hughes	#7 Handling room 1st deck, Frn. 28, stbd.	$1.33 \times 10^9$	4.4
1187	Hughes	Inside Mk 37 Director, near trainer's seat	$6.8 \times 10^9$	11.3
1191	Hughes	Passageway outside CIC, 02 deck, frn. 66	$7.7 \times 10^9$	7.9
1192	Hughes	Wardroom, frn. 49 stbd, on fwd. bulkhead	$2.4 \times 10^9$	3.8
1289	Independence	Flight Deck, fwd. port, frn. 20113	$2.24 \times 10^9$	11.6
1290	Independence	Flight deck, after port, frn. 52, stbd.	$5.98 \times 10^9$	20.6
1292	ditto	Pilot House, 05 level, frn. 52, stbd	$6.5 \times 10^{10}$	41.5
1294	ditto	Crew's Head, B-202-4L, Frn. 75, port	$2.7 \times 10^{10}$	40.5
1295	ditto	Sick Bay Head A-312-2L, Frn. 50 Stbd.	$1.8 \times 10^{10}$	9.0
1296	ditto	Machine Shop, 3rd deck, Frn. 72 Stbd.	$1.21 \times 10^{10}$	4.2
1298	ditto	Fwd. Magazine, A-513-M, Frn. WRA 50	$3.0 \times 10^{10}$	0
1299	ditto	ALPR 0208, FRN. 26, port bulkhead	$3.22 \times 10^{10}$	19.5
1300	ditto	Captains Cabin 02 deck, Frn. 44, stbd.	$3.35 \times 10^{10}$	14.3
1302	ditto	Fwd. Pilots Ready Room, C3 deck, frn. 44, port	$4.64 \times 10^{10}$	--
1303	ditto	Crew's Galley 2nd deck, Frn. 94	$1.94 \times 10^{10}$	9.1
1304	ditto	Storerroom C-412-A Frn. 127, port	$1.73 \times 10^{10}$	11.3

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Table I (continued)

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

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Table I (continued) p. lot House Port

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

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Table I (continued)

1558	Skate	Wardroom	$7.65 \times 10^{10}$	49.6
1559	ditto	ditto	$1.0 \times 10^{11}$	24.8
1560	ditto	ditto	$8.0 \times 10^{10}$	20.3
1561	ditto	ditto	$6.8 \times 10^{10}$	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. bridgewing 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/cm<sup>2</sup> in Relation to distance from Point of Detonation

Ship	Distance		No. Neutrons/cm <sup>2</sup> Observed
	Yards	Meters	
Skate	400	366	1.1 x 10 <sup>12</sup>
Independence Aft.	530	485	6.0 x 10 <sup>11</sup>
Independence Forward	600	545	2.2 x 10 <sup>11</sup>
Arkansas	610	555	5.5 x 10 <sup>10</sup>
Crittenden	660	605	3.9 x 10 <sup>10</sup>
Nevada	680	620	3.2 x 10 <sup>10</sup>
Pensacola	710	650	2.4 x 10 <sup>10</sup>
Nagato	780	713	1.3 x 10 <sup>10</sup>
ARDC-15	790	722	1.1 x 10 <sup>10</sup>
Hughes	890	813	7.7 x 10 <sup>9</sup>
Dawson	890	813	9.5 x 10 <sup>9</sup>
Apagon	950	967	4.4 x 10 <sup>9</sup>
Rhind	970	887	4.6 x 10 <sup>9</sup>
Brule	990	905	2.6 x 10 <sup>9</sup>

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